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CREW ESCAPE CAPSULE RETROROCKET CONCEPT

Volume II
SELECTION OF A RETROROCKET SYSTEM

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The objective of this analysis was to select a rocket design which would decelerate a B-1 escape capsule drop test vehicle to a vertical velocity of 10 ft/sec or less at capsule impact with the terrain. The concept is based on the prediction that if the capsule is decelerated to a vertical velocity of 10 ft/sec or less at impact, the capsule occupants would not be subjected to accelerations which exceed the requirements of MIL-C-25969B. The results of a parametric study which considered thrust to weight ratios of 2 through 10, in

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20. combination with recovery system descent rates of 30 through 60 ft/sec, are presented. The test envelopes which could be accommodated with two different off-the-shelf rocket systems are presented. The analytical method employed in determining the test envelopes is discussed. Performance summaries for the selected rocket system are given.

PREFACE

This report summarizes a crew escape capsule retrorocket demonstration and analytical program which was conducted by the Air Force Flight Dynamics Laboratory, Vehicle Equipment Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. This report consists of two volumes:

Volume I - Demonstration Program

Volume II - Selection of a Retrorocket System

The program was conducted under Project 6065, "Aerospace Vehicle Recovery and Escape Subsystems"; Task 606501, "Aerospace Vehicle Escape;" and In-House Effort 60650120, "Crew Escape Capsule Retrorocket Concept." Mr. Marvin C. Whitney of the Recovery and Crew Station Branch, AFFDL, was the Project Engineer. Mr. James M. Peters of the Recovery and Crew Station Branch conducted the analytical program.

Volume II of this report summarizes an analytical program which led to the selection of a retrorocket system for an escape capsule retrorocket impact attenuation demonstration program.

The author is indebted to many other people who contributed to this effort, including: Mr. Richard J. Dobbek, Capt. A. M. Higgins, and Mr. Lanny A. Jines of the Recovery and Crew Station Branch.

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SECTION I

INTRODUCTION

An analysis of requirements for a retrorocket impact attenuation system for a multi-crew escape capsule has been conducted, and the allowable test envelope for a full-scale demonstration program has been defined. The characteristics of the B-1 escape capsule were used in the analysis, and the demonstration program utilizes a B-1 capsule drop test "Iron Mule," B-1 recovery system, a cluster of four (4) Thiokol rockets, and a rigid, mechanical, terrain sensing system. The objective of the program was to select a rocket design which would decelerate the capsule from the recovery parachute terminal descent velocity to a vertical velocity of 10 fps or less at capsule impact with the terrain. This concept is based on the premise that if the capsule is decelerated to a vertical velocity of 10 fps or less at time of ground impact, an inflatable impact attenuator would not be required and the occupants would not be subjected to accelerations which exceed the requirements of MIL-C-25969B.

The operating envelope of the retrorocket system was to be the same as that required of the inflatable impact bag system in terms of capsule weight range, descent rate range, temperature, terrain, winds, oscillation angle, etc.

After the capsule has reached a steady-state descent rate under the recovery parachutes, rigid mechanical probes are extended beneath the capsule. Upon probe contact with the ground, an explosive energy transfer system is actuated which in turn ignites the retrorockets located between the parachutes and the capsule. The retrorockets provide the deceleration force necessary to reduce the capsule vertical descent rate to a tolerable level at impact.

This analysis effort was directed towards defining the rocket requirements and ground probe requirements for the capsule. The retrorockets provide a primary thrust level (thrust to weight ratio (T/W) greater than 1) followed by a sustainer thrust level ($T/W < 1$).

The program direction was later reorientated toward the utilization of an existing rocket (for demonstration purposes) which essentially changed the program approach from a design study to a performance evaluation. The performance analysis of existing rockets was directed toward defining a test envelope which could be accommodated by an existing rocket system, recognizing that only a portion of the capsule operational envelope could be covered. The effort prior to reorientation of the program was characterized by continually changing system parameters related to the B-1 capsule as more detailed knowledge of the system and its operation became known.

A change in the analysis technique, however, produced the most profound effect on establishing either a theoretical rocket design or an allowable test envelope for the demonstration. This change in the analysis technique consisted of combining a -5° ground slope with horizontal wind velocity in the direction of the down slope. This combination of parameters can add several feet to the vertical distance the capsule has to decrease after probe contact. This additional distance will require a sustainer T/W which approaches 1, resulting in prohibitively long sustainer burn times (thus, propellant weight is prohibitively high).

Effectively then, this particular combination of parameters precludes a rocket design of the type analyzed (two stage, fixed thrust levels) from providing acceptable impact velocities over the full operational range of the B-1 escape capsule. For the demonstration, which utilizes existing rockets, the allowable temperature range, weight range, and ground slope must all be restricted.

The original escape capsule descent and landing characteristics were selected based on existing B-1 specifications and weight status at the time of initiation of the retrorocket analysis program. These characteristics are listed below:

Weight at Impact	6921 → 7631 lbs
Vertical Descent Rate	27 → 33 fps

In addition, the escape capsule must not impact during the primary portion of the rocket burn. The following characteristics were specified for the retrorocket system:

Rocket Temperature	-65 → 160°F
Parachute Oscillation	±10°
Thrust Level Variation	±5% at any given temp.
Ground Slope	±5°
Ignition Height Error	±0.5 ft

Horizontal Wind Velocity	34 fps (20 knots)
Maximum Allowable Vertical Impact Velocity	10 fps

In order to preclude the chance of rocket plume impingement on the capsule and/or the suspension lines, a nozzle angle of 30° was originally selected. This meant an increase in required propellant weight of approximately 15.5%. The first capsule weight change increased the weight range from 6921 → 7631 lbs to 7092 → 7802 lbs, resulting in a propellant weight increase of approximately 14%. The second capsule weight change increased the weight range from 7092 → 7802 lbs to 7186 → 8165 lbs. At the same time, analysis of additional drop test data on the B-1 recovery parachute subsystem resulted in a change of the system descent rate range from 27 → 33 fps to 23 → 33 fps. Incorporating these changes resulted in a propellant weight increase of approximately 236%.

The change in the computer analysis technique, which consisted of combining the -5° ground slope with the 34 fps ground wind in the direction of the down slope, resulted in serious questions about the design of the system. For nominal thrust levels at a given temperature, the maximum impact velocity of 10 fps or less could be met although propellant weight was approaching 200 lbs. However, when the +5% thrust variation at min weight, min descent rate, max temp was applied, the capsule impact velocity, $V_I \leq 10$ fps, could not be satisfied. The reason for this was that the sustainer T/W was very near 1 at the start of sustainer burn so that when the large amount (approximately 200 lbs) of propellant was expended, the sustainer T/W exceeded 1 and the descent to the ground could not be accomplished. This indicated that the full operational envelope of the B-1 escape capsule could not be covered by the selected approach of level thrust primary rocket followed by level thrust sustainer rocket.

At this time, the difficulties enumerated above plus the status of resources and time available for design and development of a retrorocket system led to the decision to attempt to utilize existing rockets for the demonstration program. It was recognized, of course, that a much smaller envelope of parameters (temp, weight, ground slope) could be accommodated. A search of existing rocket motors revealed that the Thiokol TE-M-421 rocket motor was basically similar in thrust-time pattern to the one required. This rocket was subjected to an extensive performance analysis in order to determine the allowable test (demonstration) envelope.

The performance analysis indicated that a cluster of four Thiokol TE-M-421 rockets (with nozzle angle = 30°) could cover a test envelope as follows:

Weight at Impact	7625 → 7878 lbs
Vertical Descent Rate	24.7 → 31.3 fps
Rocket Temperature	40 → 110° F
Parachute Oscillation	±10°
Ground Slope	±1°
Ignition Height Error	±0.5 ft
Horizontal Wind Velocity	34 fps
Maximum Allowable Vertical Impact Velocity	11 fps

The descent rate range represents a 95% coverage of expected descent rates according to a statistical analysis of B-1 recovery system drop test data. The increase in the maximum allowable vertical impact velocity came about due to practical considerations of the demonstration program. If the 10 fps or less condition was to be met, the allowable weight and temperature ranges would be quite small. It was decided not to rigidize the test weights and test temperatures to avoid the possible 10% increase in the vertical impact velocity.

After the initial demonstration envelope was defined, information was received that the rocket thrust curves furnished by Thiokol were for the TE-M-421-3 motor, and the rockets which were to be delivered would be the TE-M-421-1 rocket. The -1 and the -3 rocket motors have slightly different thrust-time patterns. Basically, the -1 rocket motor has a higher peak primary thrust and a lower sustainer thrust than the -3 rocket motor (see Figure 1). Consequently, it became necessary to redefine the test envelope. The differences in the envelopes were that the capsule weight range changed to 7425 → 8075 lbs and the temperature range changed to 60 → 125°F. In addition, the rocket nozzle cant angle changed from 30° to 38°.

SECTION II

BACKGROUND

A parametric analysis which preceded this study considered retrorockets in combination with several different recovery systems. The study (Ref. 1) was based on the principle that a higher steady-state nominal descent rate could be tolerated with a retrorocket deceleration system than with the current inflatable airbag impact attenuation system.

The parametric analysis indicated that a nominal descent rate of 42 fps and a retrorocket deceleration system with primary rocket T/W = 7, followed by a time delay, and then a sustainer rocket with T/W = 0.63 could provide $V_I \leq 10$ fps over the operational envelope of the B-1 capsule, with the exception that the combination of -5° ground slope condition and the horizontal wind velocity of 34 fps is not provided for in the envelope.

This follow-on analysis program was constrained by the utilization of the present B-1 parachute recovery system and by practical considerations of rocket design and development within limited resources and program time. Therefore, the theoretical design for the demonstration concentrated on a primary rocket T/W = 5 and no time delay between primary and sustainer. The reason for selecting a system in which the sustainer fires immediately after primary burn was that it is a less complex, more reliable system. The reason for decreasing the primary rocket thrust to weight ratio from T/W = 7 to T/W = 5 was simplicity and efficiency of rocket design.

The parametric analysis revealed that a rocket system consisting of only a primary rocket could not satisfy $V_I \leq 10$ fps. Nine primary T/Ws (2 through 10) were considered for five nominal descent rates (30 through 60 fps). Two design points representing envelope extremes were used in the analysis (see Section III, Analysis Procedure). The parametric analysis also revealed that if a time delay were provided between primary thrust and sustainer thrust . weight savings could be realized. The reason for this is that at Design Point 2 (min weight, max temperature, min descent rate) the module reaches zero velocity at some point above the terrain and then starts ascending. If the sustainer fires immediately, the capsule ascends higher before it reaches zero velocity for the second time and starts descending again. However, this concept necessitates a separate rocket system for primary and sustainer rockets, in addition to providing thrust from still another source to keep the retrorocket pack properly positioned during the time delay between primary and sustainer rocket burning. Therefore, during the early phases of the design of a rocket system for a demonstration program, the concept of primary-time delay-sustainer rocket was abandoned.

The retrorocket system that resulted from the parametric study consisted of a high thrust, short burn time primary rocket and a low thrust, long burn time sustainer rocket. As noted above, during the time delay between primary and sustainer a low rocket thrust is required to keep the rocket cluster properly positioned (see Figure 2).

The primary rocket provided a nominal vertical T/W of 7 and a burn time of 0.23 sec. The sustainer rocket is ignited 0.5 sec (±20%) after ignition of the primary rocket and provides a nominal T/W of 0.63 for 2.20 sec. The total impulse of the retrorockets is 26, 742 lb-sec. The thrust vs. time curves at -65°F, 70°F and 160°F are shown in Figure 2.

The retrorocket system defined by the parametric analysis provides $V_I \leq 10$ fps for the following operational envelope:

Weight at Impact	6921 → 7631 lbs
Vertical Descent Rate	40 → 47 fps
Rocket Temperature	-65 → 160°F
Parachute Oscillation	±10°
Ignition Height Error	±0.5 ft

Figures 3 through 11 are performance curves based on the selected primary rocket thrust to weight ratio of T/W = 7, sustainer thrust to weight ratio of T/W = 0.63, and a nominal rate of descent of V_O = 42 fps.

SECTION III

ANALYSIS PROCEDURE

The parameters which affect the design of the retrorocket system are: capsule weight, capsule descent rate under the recovery parachute, retrorocket temperature, rocket ignition height variation, ground slope, parachute oscillation angle, and ground wind velocity.

As mentioned in the background section, the previous retrorocket study (Ref. 1) considered primary rocket T/Ws of 2 through 10. Figure 12 shows that the propellant weight required decreases with increasing T/W for a given descent rate range. As T/W nears 10 the loads imposed on crew and/or structure become prohibitive. The Reference 1 study selected a primary T/W of 7 for the retrorocket design. As this analysis was to be the basis for a rocket development program with a rather compact schedule, it was decided to concentrate on the T/W = 5 primary rocket since it appeared to involve a more manageable development plan, although there was a small weight penalty.

The weight range was based on available B-1 capsule weight status information. The weight range includes the difference in weight between four 5th percentile crewmen and six 95th percentile crewmen. It also includes the weight with and without the drogue parachute system since in the low speed escape mode the drogue parachute is retained with the capsule.

The capsule descent rate range was at first based on the vertical velocities at which the airbag system was to be qualified. The descent rate range was later modified based on statistical evaluation of the B-1 escape capsule recovery parachute system tests.

The ignition height variation was determined from consideration of possible deviation in the length of the rigid terrain sensing probe, capsule attitude at probe/terrain contact, variation in capsule descent rate, and variation in rocket ignition time.

The rocket temperature range is the same as the required operating temperature range of the capsule escape rockets.

The maximum allowable vertical impact velocity was based on experimental data from F-111 escape capsule drop test programs (Reference 2).

The constraint that primary rocket burnout must occur prior to ground impact was based on two considerations. The first is to ensure that impact conditions are more nearly the same as in the F-111 capsule drop test program, and the second is to preclude the possibility of bounce and secondary impact.

The parachute oscillation was defined by the B-1 escape capsule specification to be a conical oscillation of up to 10° about the vertical during steady-state descent.

Two design points representing envelope extremes are used to size a preliminary thrust-time curve and preliminary rocket ignition height. This preliminary information is then input to a two-degree-of-freedom, single body computer program for evaluation over a matrix of system parameters.

The design points are based on the following considerations. Design Point 1 determines the ignition height requirement for a specific T/W and descent rate range which determines primary burn time. Design Point 2 determines the sustainer T/W and burn time. The two design points are identified below:

Design Point 1	Design Point 2
Max Weight	Min Weight
Min Temp	Max Temp
Max Descent Rate	Min Descent Rate

The design Point 1 conditions result in the lowest actual T/W for a given nominal T/W (thrust at 70°F : average capsule weight at impact). When this minimum T/W configuration descends at the maximum descent rate, the altitude lost during primary rocket burn will be a maximum.

With the constraint that primary rocket burnout must occur before capsule impact, the primary rocket must be so designed that if it is fired at minimum ignition height rocket burnout has just occurred at impact and the descent velocity has been reduced to less than 10 fps. However, if the rocket is fired at maximum ignition height, then rocket burnout will occur above the terrain and the capsule will descend the remaining distance to the ground either under free fall or under the action of a sustainer rocket with $T/W < 1$. In either case, the velocity at primary rocket burnout must be less than 10 fps. Initial efforts were directed towards designing a retrorocket system with a primary rocket only; however, no single rocket system (of the constant thrust level type) which was evaluated approached providing an impact velocity $V_I \leq 10$ fps for the range of weights, temperatures, and vertical velocities considered.

The equations, symbols and the sequence of calculations for sizing the primary rocket are as follows:

σ	Thrust-Temperature Coefficient (0.0011/°F)
T_C	Thrust at Minimum Temperature
T_N	Thrust at Nominal Temperature
T_H	Thrust at Maximum Temperature
TE_H	Temperature, Maximum
TE_N	Temperature, Nominal
TE_C	Temperature, Minimum
VO1	Initial Capsule Vertical Weight at DP1
VO2	Initial Capsule Vertical Weight at DP2
W_L	Capsule Weight, Minimum
W_N	Capsule Weight, Nominal
W_H	Capsule Weight, Maximum

The equations and the sequence for sizing the primary rocket are as follows:

- A nominal T/W is selected for analysis and a corresponding sustainer T/W is approximated from Figure 13.

- The low temperature thrusts are calculated by equation 1.

- A value of ignition height error $E = \pm 0.5$ ft or $2\ |E| = 1.0$ ft was selected as a design goal based on previous analyses.

- V_I = maximum allowable vertical impact velocity.

- The value of the system velocity at rocket burnout, Design Point 1, V_{RB01}, is calculated from equation 2.

$$T_C = [1 + (TE_C - TE_N)(\sigma)]\ \ T_N \tag{1}$$

$$V_{RB01} = [V_I{}^2 - 2g\ (1 - T_C/W_H)\ (2\ |E|)]^{1/2} \tag{2}$$

The altitude lost during primary rocket burn at DP1 is calculated from equation 3.

$$SL_1 = \frac{V^2{}_{01} - V^2{}_{RB01}}{2g(T_C/W_H - 1)} \tag{3}$$

The primary rocket burn time is determined from equation 4.

$$t_C = \frac{V01 - V_{RB01}}{g(T_C/W_H - 1)} \tag{4}$$

The primary rocket impulse is calculated from equation 5.

$$I = (T_C)(t_C) \tag{5}$$

At Design Point 2, the actual T/W is a maximum and descent time is a minimum so that altitude lost is considerably less (than at DP1) during primary rocket burn so that the capsule may be several feet above the terrain at primary rocket burnout.

The hot rocket thrust is determined from:

$$T_H = [1 + (TE_H - TE_N)\ (\sigma)]\ T_N \tag{6}$$

The hot burn time is determined from:

$$t_H = I/T_H \tag{7}$$

which allows us to calculate the value of the system velocity at rocket burnout, Design Point 2:

$$V_{RB02} = V02 - t_H\ g(T_H/W_L - 1) \tag{8}$$

and the altitude lost at DP2 from:

$$SL_2 = \frac{VO2^2 - V^2_{RBO2}}{2g(T_H/W_L - 1)} \tag{9}$$

Since SL2 < SL1, the height above the terrain will be greater than 2 |E|. The sustainer rocket T/W required to allow V_I = 10 fps is calculated from

$$(T_H/W_L) = 1 - \frac{V^2_I - V^2_{RBO2}}{2g\ (SL1 - SL2 + 2|E|)} \tag{10}$$

The sustainer burn time is then calculated from:

$$t_H = \frac{VI - V_{RBO2}}{g\ (1 - (T_H/W_L))} \tag{11}$$

The (T_H/W_L) thus obtained is converted to the T_C/W_H, and V_I is evaluated at DP1. If this value is less than the maximum allowable, the thrust time curves for -65°F, 70°F and 160°F, and the ignition heights obtained from:

$$IHmin = SL1 \tag{12}$$

and

$$IHmax = SL1 + 2\ |E| \tag{13}$$

are input into the single body, two-degree-of-freedom computer program (see Appendix A).

If $V_I > 10$ fps, the minimum ignition height is increased and impulse is added to the primary rocket in the form of additional burn time. This "new rocket" is then re-evaluated at DP2, the T/W for the sustainer recomputed, and so on until the two design points both indicate $V_I \leq 10$ fps. This computer program considers parachute drag and capsule base drag, and rocket thrust buildup and tail-off. The program output is a history of module acceleration, velocity, height above the terrain, rocket total thrust, vertical thrust and impulse.

As mentioned previously, the two design points were selected as performance envelope extremes. DP1 determines the primary rocket impulse and IHmin for a given T/W and E. DP2 sizes the sustainer rocket and since it influences allowable V_{RBO1} it influences the primary rocket design during the iterative process. However, other combinations of the influencing parameters within the performance envelope could produce impact velocities of approximately 10 fps, especially when the effects of parachute drag and thrust buildup and tail-off are considered. Therefore, a large matrix of parameter combinations was evaluated within the computer program.

SECTION IV

THEORETICAL ROCKETS

The first phase of this effort was directed towards establishing a rocket design suitable for the full-scale demonstration of the retro-rocket deceleration system.

At that time, the analysis technique of subjecting the mathematical model to a combination of -5° ground slope and 20 knot ground wind had not evolved. Consequently, it appeared that the full operational envelope of the B-1 crew escape capsule could be accommodated with no weight penalty over the airbag system, and quite possibly with a weight savings. The previous parametric study indicated that a greater weight savings was possible because of the higher descent rate under the recovery system (therefore, a lower recovery system weight) combined with a retrorocket system with primary T/W = 7. As shown in Figure 12, there is a weight savings with increasing primary T/W. The higher primary T/W rocket systems, however, are extremely short burn time systems, making them less attractive from a rocket design standpoint. As this phase of the study developed, it was decided to concentrate on a rocket system with T/W = 5 instead of T/W = 7.

Figures 14 through 16 show the thrust histories for T/W = 3, 5, and 7 at that point in time when the capsule weight range was 7092 → 7802 lbs and the descent rate range was 27 → 33 fps. Referring to Figure 12, the system propellant weight for the T/W = 7 rocket is approximately 41 lbs. Analysis indicates that if a time delay were used between the primary and sustainer rockets, the propellant weight would be 36.5 lbs. However, as mentioned previously, in spite of the weight savings it was decided not to include a time delay in the system for reasons of simplicity and reliability.

Figures 17 through 19 show the retrorocket performance at Design Points 1 and 2. It is noted that at that time the retrorocket systems shown in Figures 14 through 16 met the operational envelope requirements of the B-1 crew escape capsule.

The next change in the operational envelope for the retrorocket system was an increase in weight range from 7092 → 7802 lbs to 7186 → 8165 lbs and an increase in the descent rate range from 27 → 33 to 23 → 33 ft/sec. These changes resulted in a major weight increase in the system propellant weight (e.g., the propellant weight for the T/W = 5 rocket increased from 48 to 112 lbs).

When the -5° ground slope, 20 knot ground wind condition was applied, the propellant weight for the T/W = 5 rocket increased from 112 lbs to 190 lbs for the nominal thrust level condition. The system was now approaching weight levels which no longer made it competitive with the airbags.

When the +5% thrust level condition was applied to the T/W = 5 system, the T/W under the sustainer (which increases with time since W decreases) approached 1 so that in effect the capsule was almost suspended above the ground until rocket burnout. An attempt was made to increase sustainer burn time but this resulted in sustainer T/W > 1 after a certain time so that the capsule began to ascend rather than descend.

It is recognized that the +5% thrust level, at a given temperature, would likely only occur for the rocket system if there was a single rocket (with multiple nozzles) which made up the retrorocket system. If multiple rockets (say 3 or 4) made up the retrorocket system, then the +5% thrust level at a given temperature could reasonably be neglected (since it is probable that not all rockets would be +5% thrust).

At this point in time, the program direction changed from theoretical rockets to an analysis of off-the-shelf rockets which could be employed in the demonstration. Therefore, no further work was directed towards refining the theoretical T/W = 5 retrorocket system.

SECTION V

PERFORMANCE ANALYSIS

1. ROCKET MOTOR TE-M-421-3

The original Thiokol rocket which was evaluated for use in the demonstration program was the TE-M-421-3 shown in Figure 20. The 90° nozzle angle shown can be modified to any angle between 0 and 90°.

Preliminary analysis showed that four of the rockets would be required and the nozzle cant angle would be approximately 30°. The nominal ignition height was 9.25 ft (8.75 min, 9.75 max). Data was provided by Thiokol for thrust vs. time at 60 and 120°F. Thrust vs. time data for intermediate temperatures at 10° increments was extrapolated from these two curves and subjected to a comprehensive computer analysis in order to determine the exact nozzle angle required for the rockets and the allowable range of test variables.

The allowable range of test parameters is as shown below for this rocket system:

Weight at Impact	7625 → 7878 lbs
Vertical Descent Rate	24.7 → 31.3 fps
Rocket Temperature	40 → 110°F
Parachute Oscillation	+10°
Ground Slope	+1°
Ignition Height Error	+0.5 ft
Horizontal Wind Velocity	34 fps
Max Allowable Vertical Impact Velocity	11 fps

During the evaluation of the TE-M-421-3 rocket, the change in analysis technique occurred (that of combining -5° ground slope with the 20 knot horizontal wind at DP2). Computer analysis indicated that the ground slope must be held to ±1° in order to cover even the limited range of test variables listed above.

2. ROCKET MOTOR TE-M-421-1

Original analyses of the Thiokol rocket were for the TE-M-421-3 rocket motor. The rocket which was actually utilized was the TE-M-421-1 rocket motor. The differences in the thrust histories of the two rockets are shown in Figure 1. After this program change, the performance analysis had to be reinstituted. The evaluation of the -1 rocket motor showed that the nozzle angle had to be changed from 30° to 38° and the nominal ignition height changed from 9.25 ft to 7.60 ft (7.1 min, 8.1 max).

Thrust time data was provided for temperatures of 60 and 125°F. Thrust histories for three intermediate temperatures (76.25, 92.5 and 108.75°F) were extrapolated from these two curves. These thrust histories are shown in Figures 21 through 25.

A summary of the results of 1000 computer runs is shown in Table I.

The -1 rocket motor enabled the test weight range to be expanded from 7675 → 7878 lbs to 7425 → 8075 lbs and changed the demonstration temperature range from 40 → 110°F to 60 → 125°F. The performance of the -1 rocket motor at DP1 and DP2 is shown in Figures 26 through 28.

Subsequent to the completion of the evaluation of the -1 rocket motor, Thiokol provided data from 12 motor firings at temperatures of -20, 60, and 125°F. Check runs of these thrust time histories at DP1 and DP2 indicate that the capsule impact velocities would fall within the maximum allowable for the test envelope established previously.

SECTION VI

CONCLUSIONS

1. The analysis of a retrorocket deceleration system for the B-1 escape capsule has shown that the full operational envelope of the escape capsule configuration under investigation cannot be satisfied if the maximum impact velocity is 10 fps and the rocket characteristics are level thrust primary and level thrust sustainer. An evaluation of the probability of encountering all of the envelope extremes and combinations of the extremes may show that the design approach of this study was overly conservative.

2. It appears that the operational envelope is too broad for a fixed rocket, fixed ignition height system. Therefore, either the design envelope has to be reduced statistically or physically by methods such as rocket temperature control and capsule weight range control, or the system must incorporate some form of variable thrust and/or variable ignition height retrorocket system.

3. The analysis shows that a fixed thrust level, fixed ignition height rocket system can be demonstrated for a limited portion of the operational envelope utilizing existing retrorocket systems and state-of-the-art mechanical probe systems.

REFERENCES

1. Babish, C.A., et al. "A Parachute/Retrorocket Landing System for Aeronautical Vehicles," Unpublished Data, AFFDL/FER, 1974.

2. Peterson, R.L. and Roberts, E.O., "Experimental Investigation of the Ground Impact Characteristics of a Full-Scale Aircraft Emergency Escape Capsule System," AFFDL-TR-72-34, July 1972.

TABLE I

SUMMARY OF IMPACT VELOCITIES - TE-M-421-1

ROCKET ANGLE: 38° IGNITION HEIGHT: 8.1 FT

GROUND SLOPE: -1° HORIZ. VELOCITY: 34 FPS

START RUN #		1	26	51	76	101	126	151	176	201	226
END RUN #		25	50	75	100	125	150	175	200	225	250
TEMP °F		60		76.25		92.5		108.75		125	
OSCILLATION ANGLE (DEG)		0	10	0	10	0	10	0	10	0	10
WEIGHT (LBS)	SINK RATE (FPS)	VERTICAL VELOCITY AT IMPACT (FPS)									
8075	31.3	10.41	10.71	10.69	11.00	10.38	10.68	10.03	10.32	10.37	10.66
"	29.65	10.07	10.34	10.33	10.60	10.12	10.37	9.86	10.11	10.21	10.45
"	26.35	10.09	10.27	10.41	10.57	10.34	10.50	10.27	10.42	10.62	10.77
"	24.7	10.36	10.50	10.69	10.83	10.67	10.81	10.65	10.78	10.96	11.09
7875	31.3	10.02	10.33	10.32	10.62	10.01	10.31	9.68	9.96	10.04	10.32
"	29.65	9.78	10.04	10.05	10.30	9.85	10.09	9.63	9.86	9.99	10.21
"	28.0	9.76	9.97	10.06	10.26	9.95	10.13	9.84	10.02	10.22	10.38
"	26.35	9.97	10.13	10.31	10.47	10.26	10.42	10.21	10.35	10.56	10.70
"	24.7	10.33	10.45	10.65	10.78	10.64	10.76	10.64	10.76	10.95	11.07
7675	31.3	9.65	9.95	9.93	10.24	9.66	9.95	9.36	9.63	9.73	9.99
"	29.65	9.49	9.73	9.77	10.02	9.60	9.83	9.42	9.64	9.81	10.01
"	28.0	9.58	9.78	9.91	10.09	9.83	10.00	9.75	9.90	10.14	10.29
"	26.35	9.88	10.03	10.23	10.38	10.20	10.35	10.18	10.32	10.53	10.67
"	24.7	10.31	10.43	10.61	10.74	10.62	10.75	10.66	10.77	10.96	11.07
7550	31.3	9.42	9.71	9.71	10.00	9.45	9.73	9.17	9.43	9.55	9.81
"	29.65	9.33	9.57	9.61	9.85	9.47	9.68	9.32	9.52	9.72	9.90
"	28.0	9.47	9.67	9.82	10.00	9.77	9.93	9.70	9.85	10.10	10.24
"	26.35	9.84	9.98	10.19	10.34	10.19	10.32	10.18	10.31	10.54	10.66
"	24.7	10.32	10.43	10.60	10.72	10.63	10.74	10.68	10.79	10.99	11.09
7425	31.3	9.19	9.48	9.48	9.77	9.25	9.51	9.00	9.25	9.39	9.63
"	29.65	9.16	9.40	9.48	9.70	9.36	9.56	9.23	9.41	9.65	9.83
"	28.0	9.40	9.57	9.76	9.93	9.71	9.87	9.68	9.81	10.07	10.21
"	26.35	9.82	9.95	10.16	10.30	10.17	10.30	10.19	10.31	10.54	10.66
"	24.7	10.35	10.46	10.60	10.72	10.64	10.76	10.72	10.82	11.01	11.12

TABLE I (Continued)

ROCKET ANGLE: 38°   IGNITION HEIGHT: 8.1 FT

GROUND SLOPE: +1°   HORIZ. VELOCITY: 34 FPS

START RUN #		251	276	301	326	351	376	401	426	451	476
END RUN #		275	300	325	350	375	400	425	450	475	500
TEMP °F		60		76.25		92.5		108.75		125	
OSCILLATION ANGLE (DEG)		0	10	0	10	0	10	0	10	0	10
WEIGHT (LBS)	SINK RATE (FPS)	VERTICAL VELOCITY AT IMPACT (FPS)									
8075	31.3	9.76	10.04	10.07	10.35	9.69	9.95	9.26	9.50	9.63	9.88
"	29.65	9.27	9.47	9.54	9.76	9.24	9.45	8.92	9.09	9.27	9.43
"	28.0	9.00	9.14	9.27	9.40	9.06	9.18	8.83	8.93	9.19	9.27
"	26.35	8.97	9.04	9.25	9.30	9.13	9.17	9.00	9.00	9.37	9.36
"	24.7	9.14	9.14	9.47	9.44	9.41	9.38	9.34	9.29	9.69	9.64
7875	31.3	9.32	9.59	9.64	9.91	9.27	9.52	8.86	9.08	9.23	9.45
"	29.65	8.90	9.09	9.18	9.38	8.90	9.08	8.60	8.75	8.96	9.10
"	28.0	8.73	8.85	9.00	9.11	8.82	8.91	8.63	8.68	8.99	9.03
"	26.35	8.78	8.82	9.08	9.11	8.99	8.98	8.90	8.86	9.28	9.04
"	24.7	9.04	9.00	9.38	9.34	9.34	9.28	9.30	9.22	9.65	9.57
7675	31.3	8.89	9.14	9.20	9.46	8.85	9.08	8.45	8.66	8.83	9.04
"	29.65	8.54	8.72	8.83	9.01	8.58	8.73	8.31	8.43	8.68	8.79
"	28.0	8.46	8.55	8.75	8.83	8.60	8.65	8.44	8.47	8.84	8.84
"	26.35	8.62	8.63	8.95	8.94	8.88	8.84	8.81	8.75	9.19	9.14
"	24.7	8.95	8.89	9.31	9.25	9.29	9.21	9.28	9.17	9.63	9.53
7550	31.3	8.61	8.85	8.92	9.17	8.58	8.80	8.21	9.41	8.59	8.78
"	29.65	8.33	8.49	8.62	8.78	8.38	8.52	8.13	8.23	8.52	8.60
"	28.0	8.30	8.39	8.60	8.68	8.48	8.51	8.35	8.35	8.76	8.73
"	26.35	8.53	8.51	8.88	8.85	8.83	8.[illegible]7	8.77	8.70	9.17	9.08
"	24.7	8.93	8.84	9.28	9.20	9.28	9.18	9.28	9.16	9.63	9.51
7425	31.3	8.34	8.57	8.65	8.88	8.32	8.53	7.97	8.15	8.36	8.53
"	29.65	8.12	8.27	8.41	8.56	8.20	8.31	7.97	8.04	5.38	8.42
"	28.0	8.16	8.22	8.48	8.52	8.38	8.38	8.28	8.24	8.70	8.65
"	26.35	8.45	8.42	8.82	8.77	8.79	8.72	8.75	8.65	9.15	9.05
"	24.7	8.92	8.81	9.26	9.16	9.27	9.15	9.81	9.16	9.66	9.51

TABLE I (Continued)

ROCKET ANGLE: 38° IGNITION HEIGHT: 8.1 FT

GROUND SLOPE: 0° HORIZ. VELOCITY: 34 FPS

START RUN #		501	526	551	576	601	626	651	676	701	726
END RUN #		525	550	575	600	625	650	675	700	725	750
TEMP °F		60		76.25		92.5		108.75		125	
OSCILLATION ANGLE (DEG)		0	10	0	10	0	10	0	10	0	10
WEIGHT (LBS)	SINK RATE (FPS)	VERTICAL VELOCITY AT IMPACT (FPS)									
8075	31.3	10.07	10.35	10.37	10.66	10.02	10.29	9.63	9.89	9.99	10.25
	29.65	9.65	9.89	9.92	10.15	9.66	9.88	9.37	9.57	9.73	9.91
"	28.0	9.47	9.65	9.74	9.91	9.57	9.73	9.38	9.52	9.75	9.86
"	26.35	9.52	9.63	9.81	9.92	9.72	9.82	9.64	9.71	9.99	10.06
'	24.7	9.74	9.81	10.08	10.14	10.04	10.08	10.00	10.03	10.33	10.36
7875	31.3	9.67	9.94	9.96	10.24	9.62	9.89	9.25	9.50	9.62	9.86
"	29.65	9.32	9.54	9.59	9.81	9.36	9.56	9.10	9.27	9.46	9.62
"	28.0	9.23	9.39	9.51	9.66	9.36	9.49	9.22	9.32	9.59	9.68
"	26.35	9.36	9.46	9.69	9.77	9.62	9.68	9.55	9.59	9.92	9.96
"	24.7	9.67	9.71	10.01	10.06	9.99	10.02	9.97	9.99	10.31	10.32
7675	31.3	9.25	9.53	9.55	9.82	9.24	9.49	8.89	9.12	9.26	9.49
"	29.65	9.00	9.21	9.28	9.49	9.07	9.26	8.85	9.00	9.23	9.36
"	28.0	9.00	9.15	9.30	9.44	9.19	9.30	9.09	9.16	9.49	9.55
"	26.35	9.24	9.31	9.59	9.64	9.55	9.59	9.50	9.52	9.86	9.90
"	24.7	9.64	9.66	9.97	10.00	9.96	9.98	9.98	9.97	10.31	10.31
7550	31.3	9.00	9.26	9.30	9.55	8.99	9.25	8.68	8.89	9.04	9.26
"	29.65	8.51	9.01	9.10	9.29	8.91	9.07	8.71	8.84	9.09	9.23
"	28.0	8.88	9.00	9.20	9.31	9.10	9.20	9.01	9.08	9.43	9.47
"	26.35	9.18	9.23	9.54	9.59	9.50	9.54	9.48	9.50	9.85	9.87
"	24.7	9.63	9.64	9.95	9.97	9.96	9.96	10.00	9.98	10.32	10.31
7425	31.3	8.75	9.00	9.05	9.30	8.77	8.99	8.46	8.67	8.85	9.05
"	29.65	8.63	8.81	8.92	9.09	8.75	8.91	8.58	8.70	8.99	9.10
"	28.0	8.77	8.87	9.10	9.19	9.04	9.11	8.97	9.02	9.39	9.42
"	26.35	9.12	9.17	9.49	9.54	9.48	9.50	9.48	9.47	9.85	9.85
"	24.7	9.64	9.63	9.94	9.94	9.96	9.95	10.03	9.99	10.34	10.32

TABLE I (Concluded)

ROCKET ANGLE: 38° IGNITION HEIGHT: 8.1 FT

GROUND SLOPE: -2° HORIZ. VELOCITY: 34 FPS

START RUN #		751	776	801	826	851	876	901	926	951	976
END RUN #		775	800	825	850	875	900	925	950	975	1000
TEMP °F		60		76.25		92.5		108.75		125	
OSCILLATION ANGLE (DEG)		0	10	0	10	0	10	0	10	0	10
WEIGHT (LBS)	SINK RATE (FPS)	VERTICAL VELOCITY AT IMPACT (FPS)									
8075	31.3	10.78	11.11	11.05	11.38	10.77	11.10	10.45	10.78	10.79	11.12
"	29.65	10.52	10.83	10.79	11.09	10.59	10.89	10.39	10.69	10.74	11.03
"	28.0	10.49	10.78	10.79	11.07	10.69	10.95	10.58	10.84	10.94	11.19
"	26.35	10.68	10.93	11.01	11.26	10.96	11.21	10.91	11.15	11.25	11.49
"	24.7	11.00	11.22	11.31	11.53	11.29	11.52	11.30	11.52	11.58	11.81
7875	31.3	10.42	10.76	10.70	11.03	10.43	10.77	10.15	10.48	10.50	10.83
"	29.65	10.26	10.56	10.53	10.84	10.37	10.67	10.20	10.49	10.57	10.85
"	28.0	10.[illegible]	10.60	10.64	10.90	10.56	10.83	10.49	10.74	10.86	11.11
"	26.35	10.59	10.84	10.93	11.18	10.91	11.15	10.88	11.12	11.22	11.45
"	24.7	10.98	11.21	11.26	11.50	11.27	11.50	11.30	11.53	11.55	11.82
7675	31.3	10.07	10.42	10.36	10.70	10.13	10.4[illegible]	9.88	10.20	10.24	10.56
"	29.65	10.00	10.31	10.31	10.60	10.18	10.47	10.04	10.32	10.43	10.72
"	28.0	10.18	10.45	10.53	10.78	10.47	10.73	10.42	10.67	10.79	11.04
"	26.35	10.54	10.78	10.87	11.12	10.87	11.10	10.87	11.11	11.21	11.45
"	24.7	11.00	11.22	11.24	11.48	11.27	11.50	11.33	11.56	11.60	11.84
7550	31.3	9.87	10.21	10.15	10.48	9.95	10.27	9.72	10.04	10.10	10.41
"	29.65	9.87	10.17	10.18	10.47	10.07	10.35	9.97	10.25	10.37	10.64
"	28.0	10.10	10.38	10.47	10.73	10.42	10.69	10.39	10.65	10.76	11.02
"	[illegible].35	10.52	10.77	10.85	11.10	10.85	11.10	10.88	11.12	11.21	11.45
"	24.7	11.02	11.25	11.24	11.47	11.29	11.52	11.36	11.59	11.63	11.86
7425	31.3	9.67	10.00	9.96	10.29	9.77	10.10	9.57	9.89	9.99	10.28
"	29.65	9.74	10.04	10.07	10.35	9.98	10.27	9.91	10.18	10.31	10.59
"	28.0	10.05	10.32	10.41	10.68	10.39	10.65	10.38	10.63	10.76	11.01
"	26.35	10.54	10.77	10.84	11.08	10.86	11.10	10.91	11.14	11.23	11.47
"	24.7	11.04	11.27	11.24	11.48	11.90	11.54				

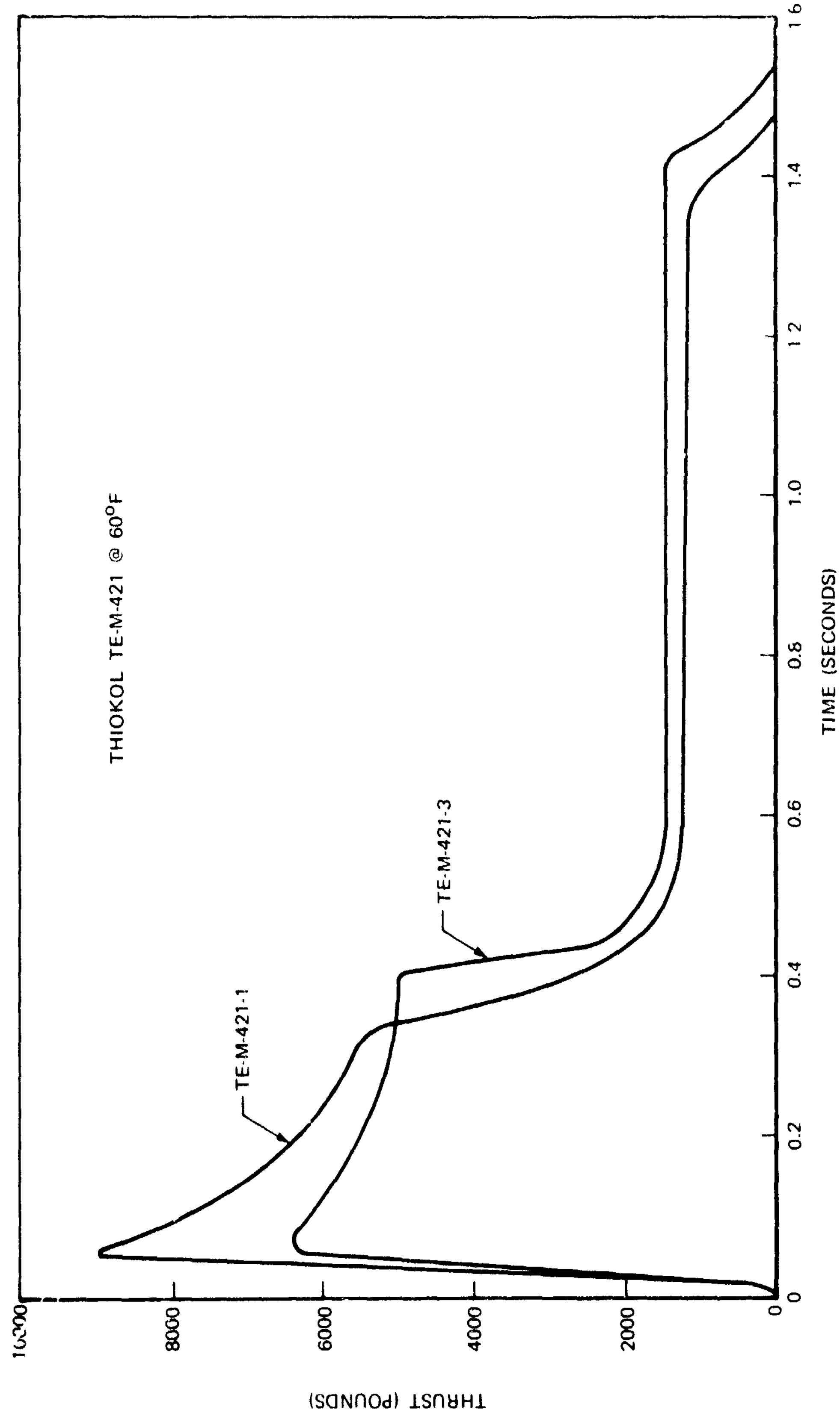


Figure 1. Thrust Versus Time for TE-M-421-1 and TE-M-421-3 at 60°F

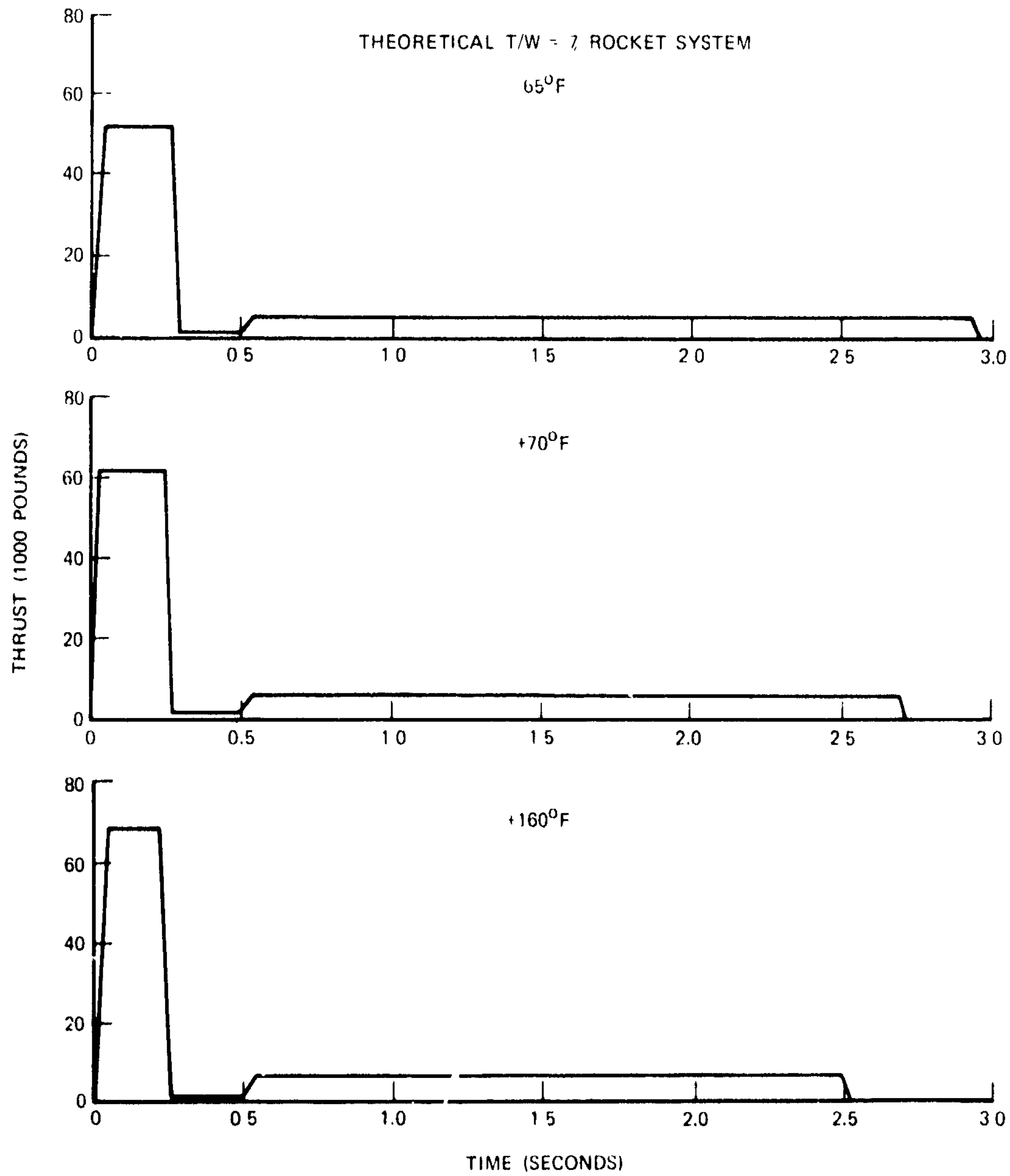


Figure 2. Thrust Versus Time for T/W = 7 Rocket at -65, 70, and 160°F

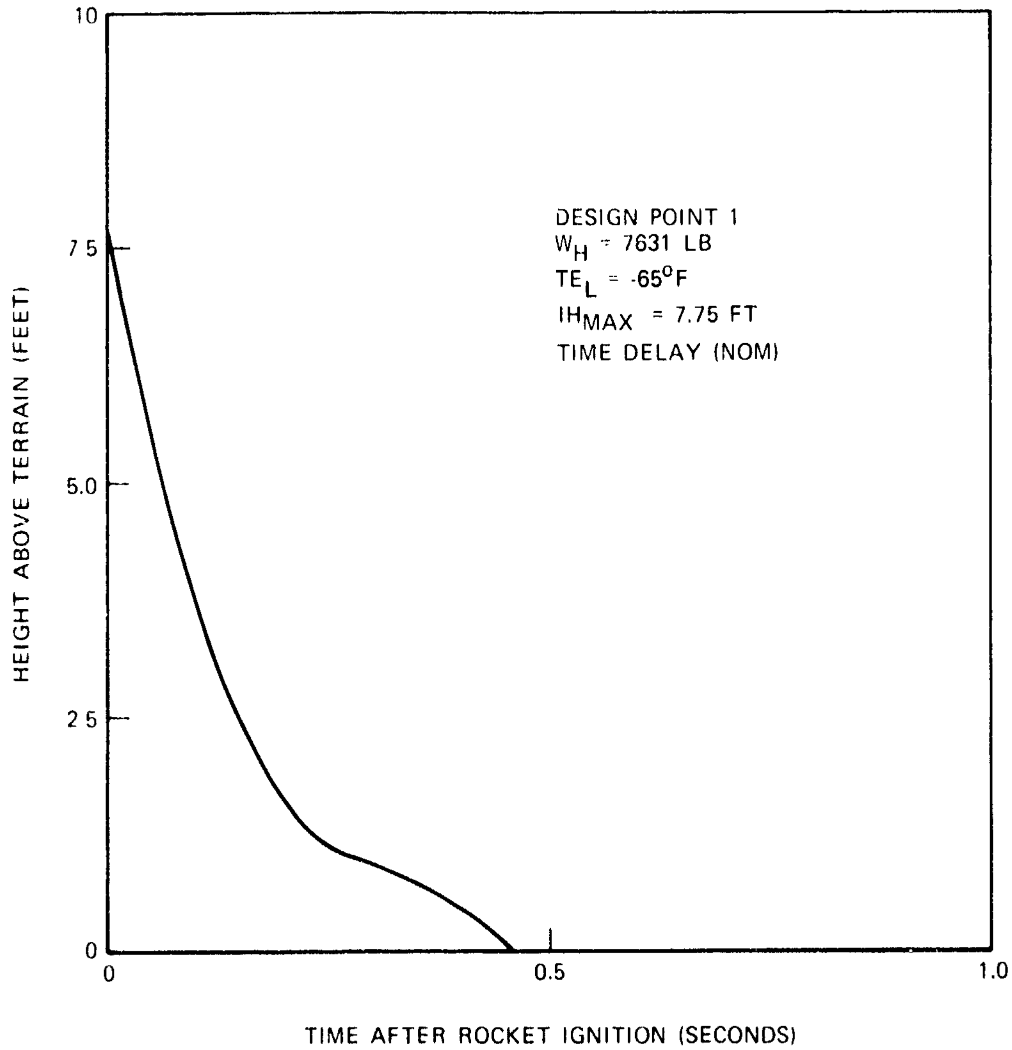


Figure 3. Height Above Terrain Versus Time After Rocket Ignition at Design Point 1

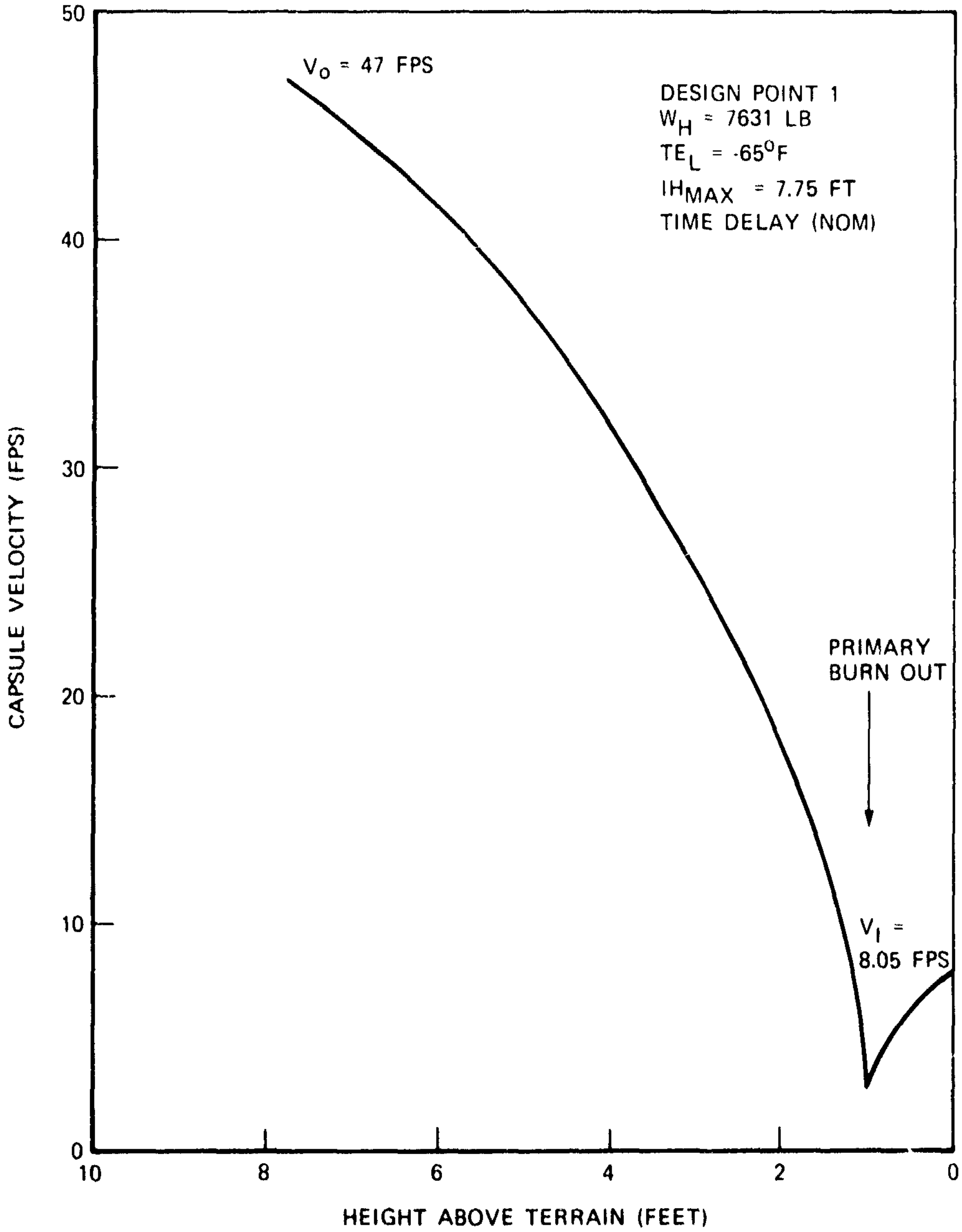


Figure 4. Capsule Velocity Versus Height Above Terrain at Design Point 1

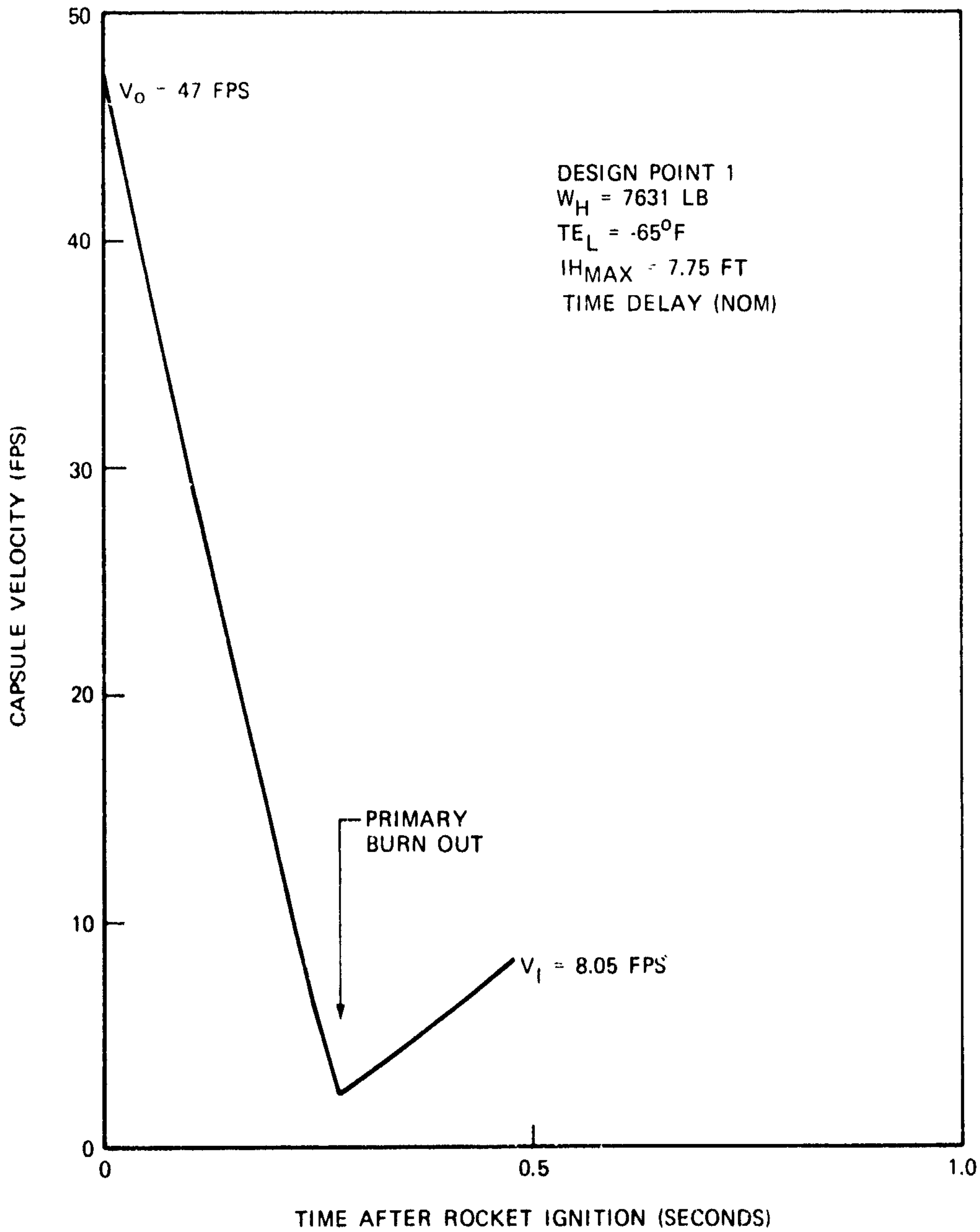


Figure 5. Capsule Velocity Versus Time After Rocket Ignition at Design Point 1

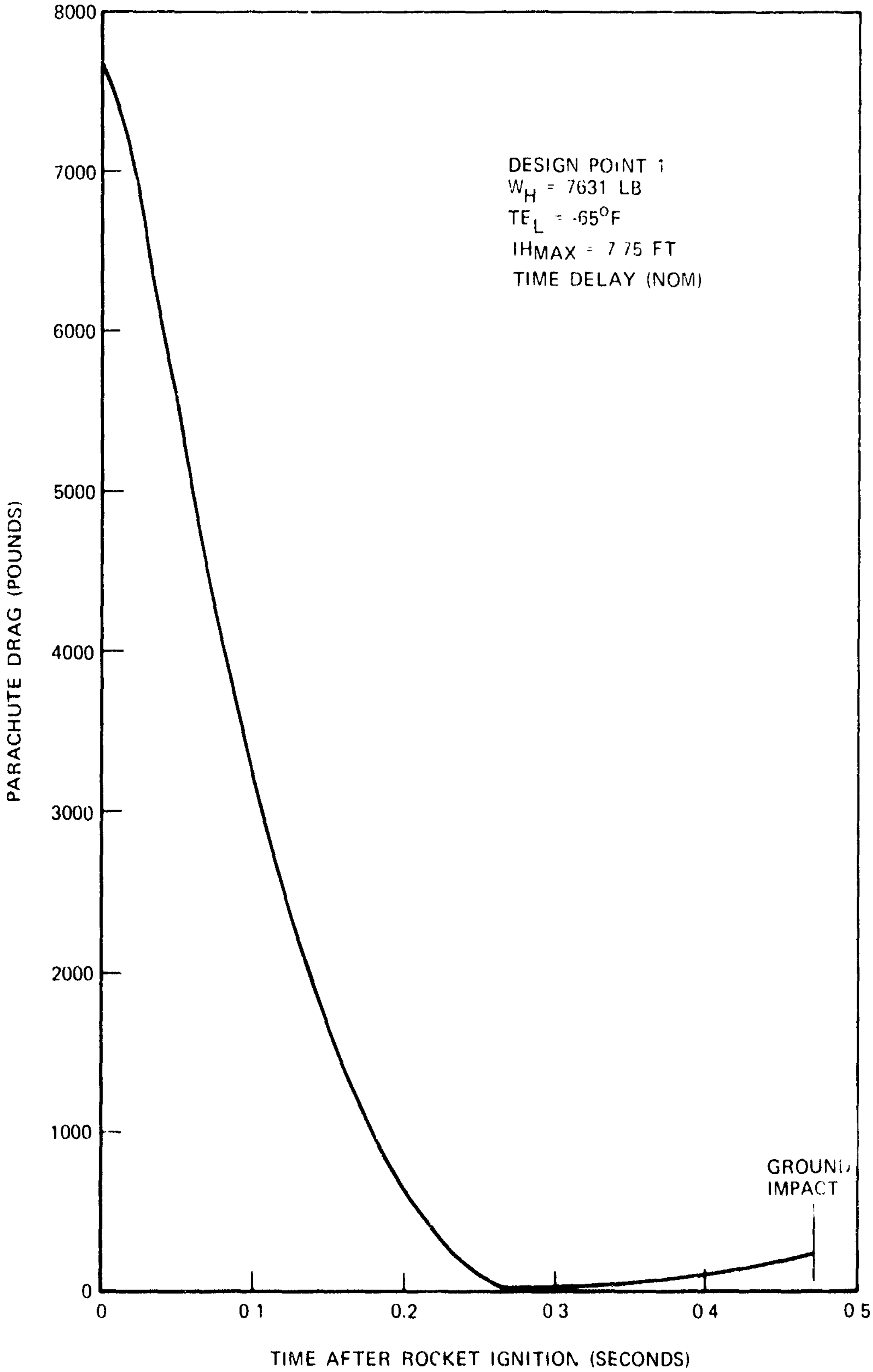


Figure 6. Parachute Drag Versus Time After Rocket Ignition at Design Point 1

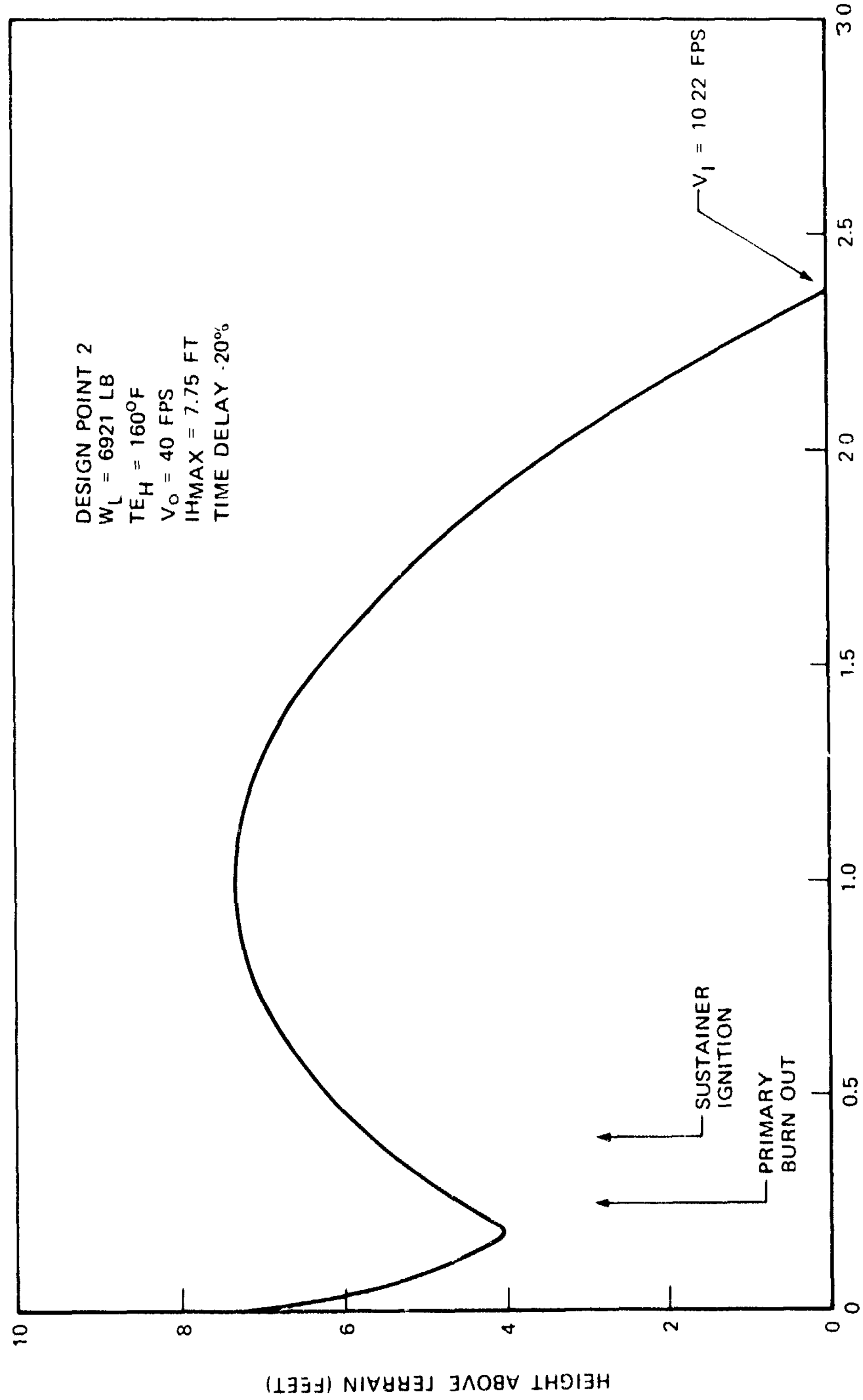


Figure 7. Height Above Terrain Versus Time After Rocket Ignition at Design Point 2

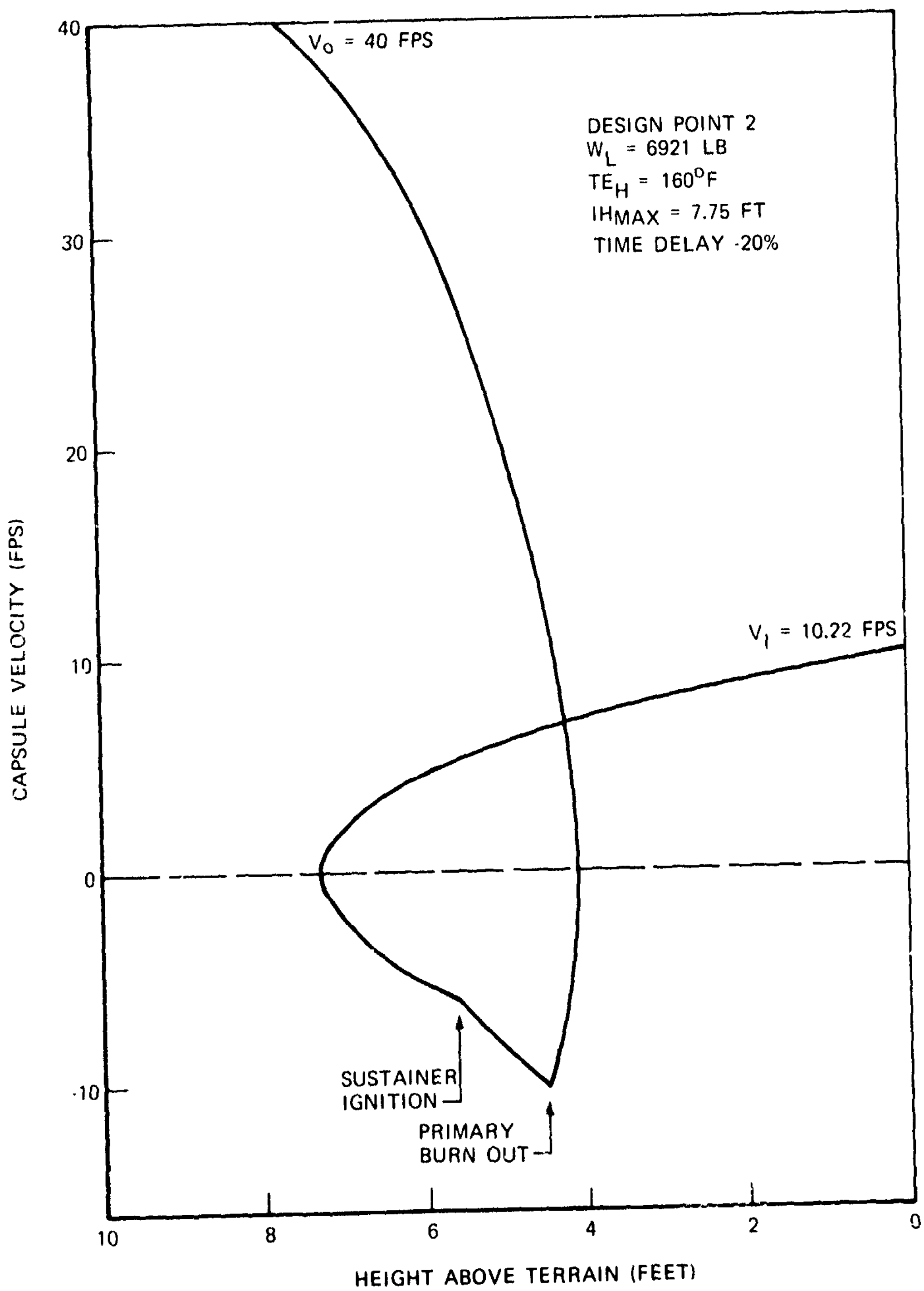


Figure 8. Capsule Velocity Versus Height Above Terrain at Design Point 2

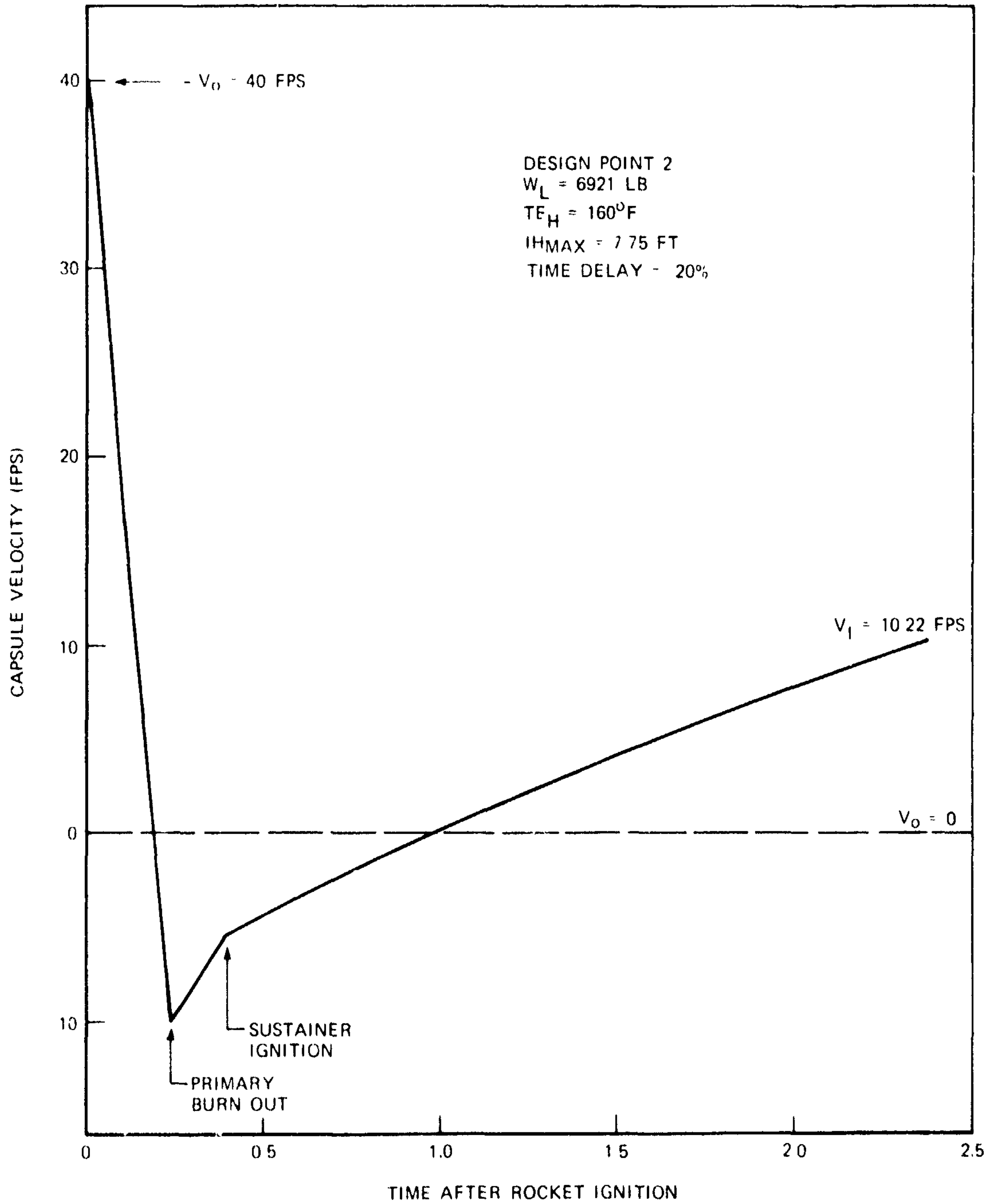


Figure 9. Capsule Velocity Versus Time After Rocket Ignition at Design Point 2

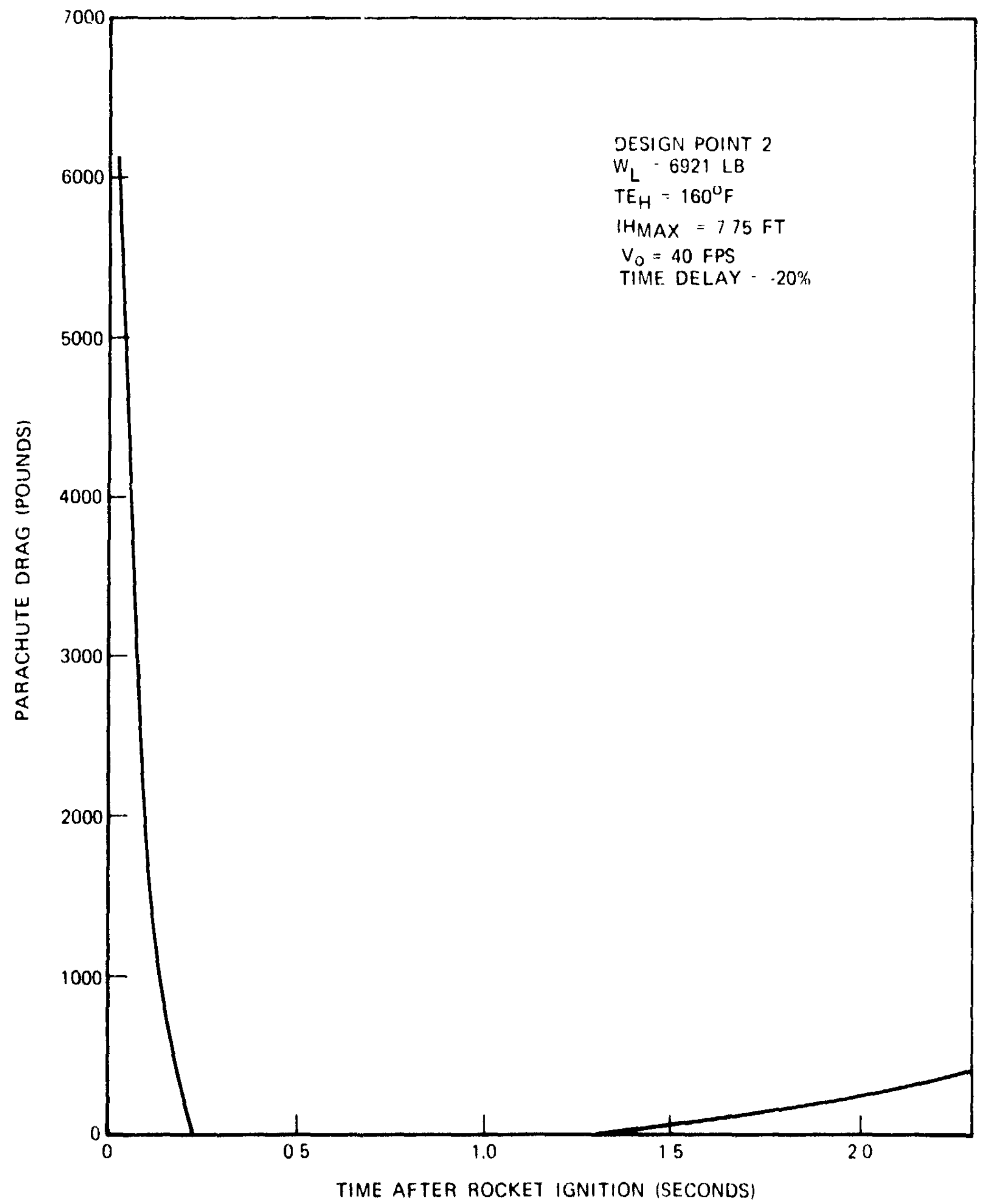


Figure 10. Parachute Drag Versus Time After Rocket Ignition at Design Point 2

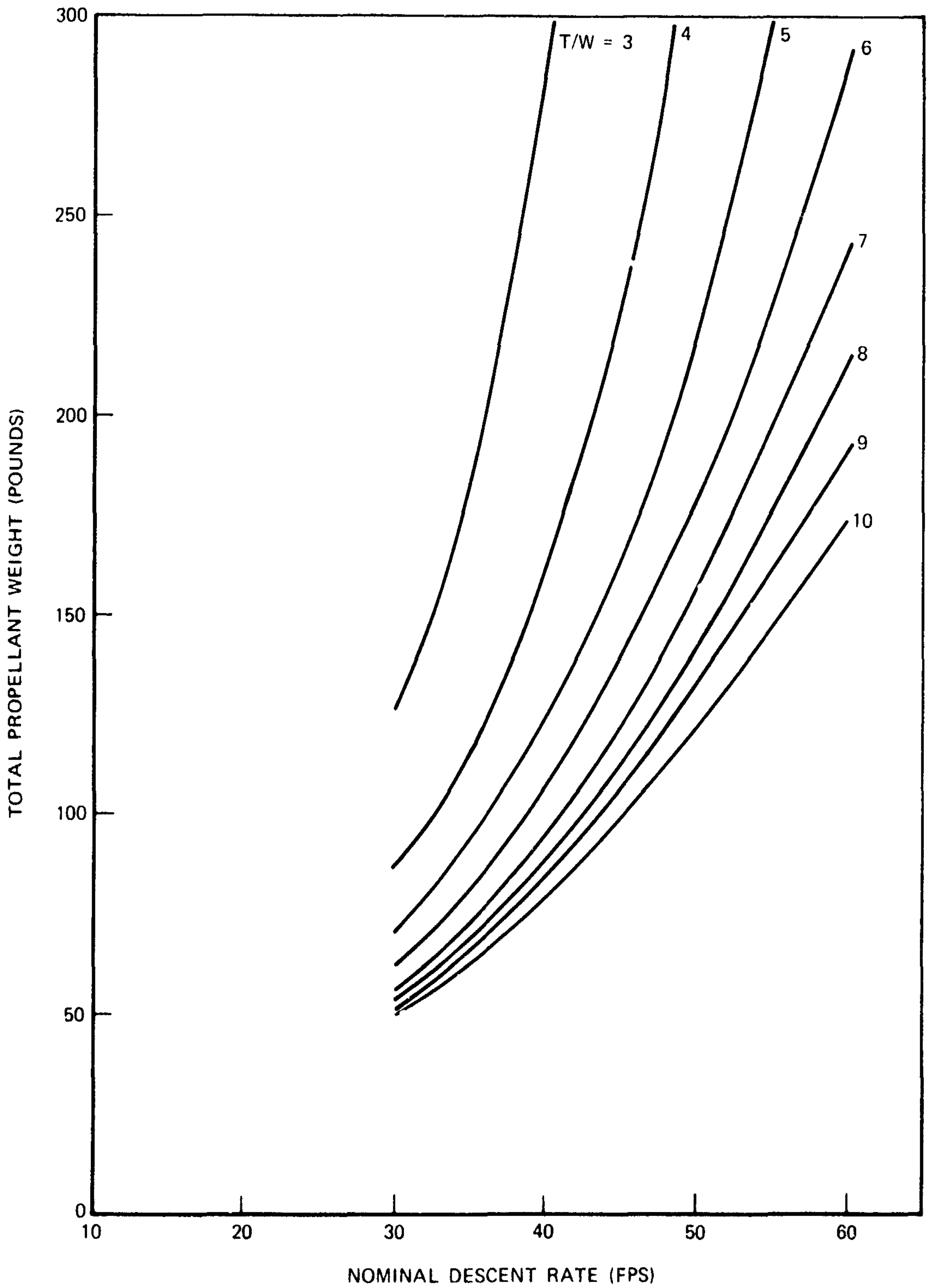


Figure 11. Total Propellant Weight as a Function of Descent Rate and Primary T/W

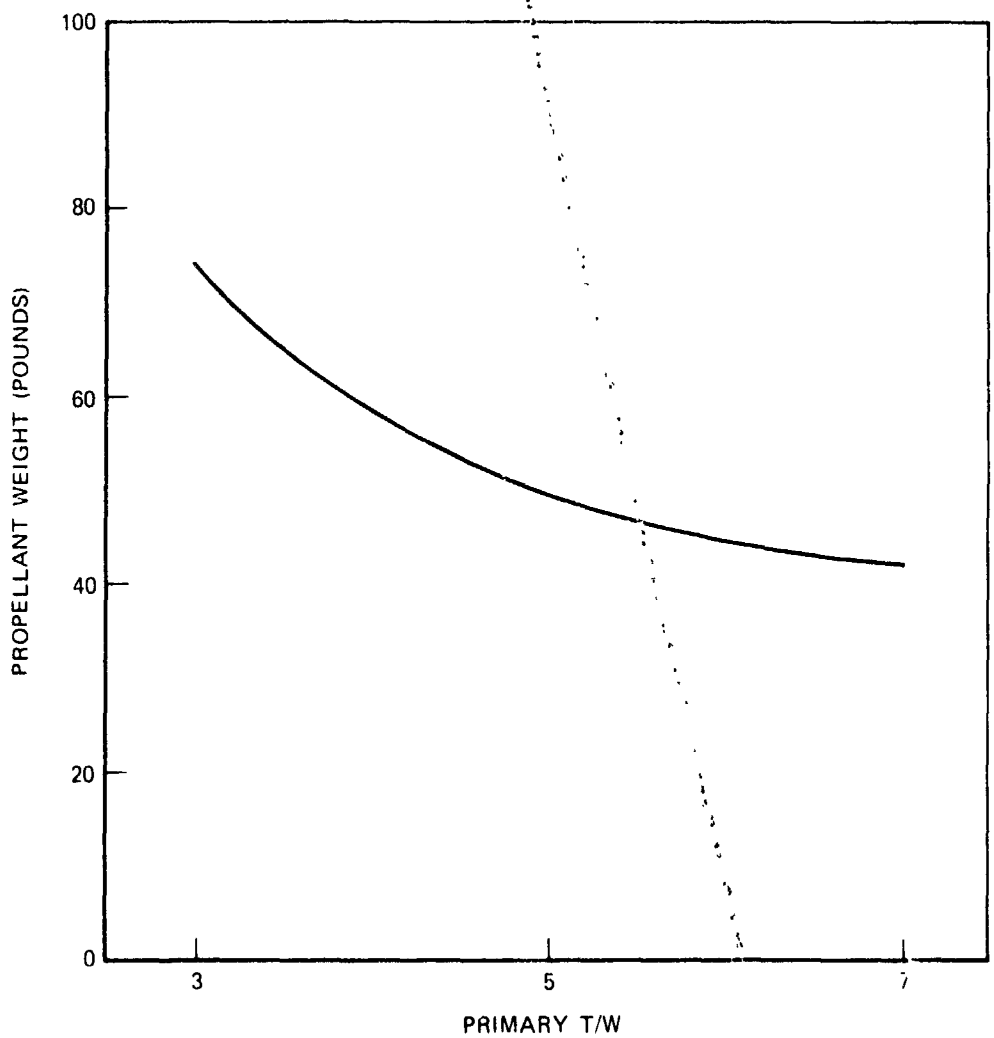


Figure 12. Total Propellant Weight (No Time Delay) as a Function of Primary T/W

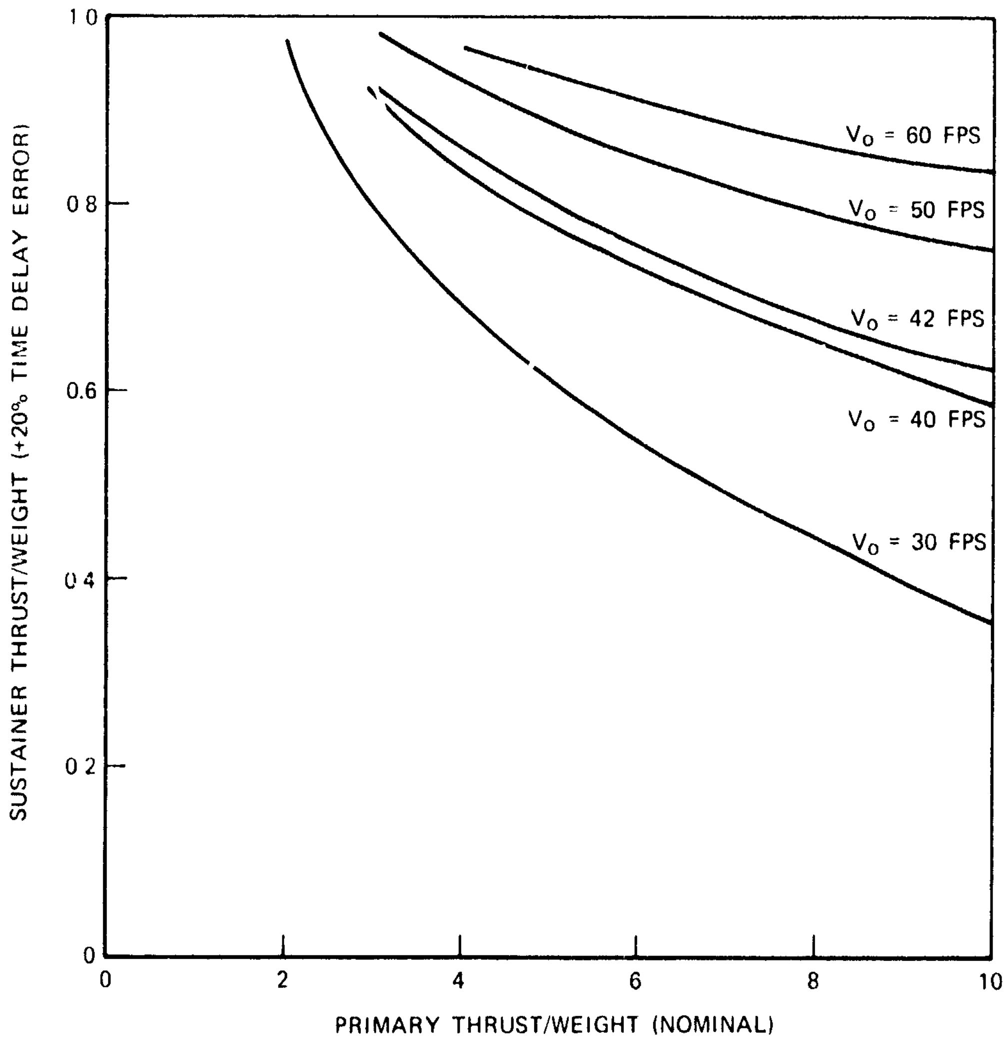


Figure 13. Sustainer T/W (20% Time Delay Error) as a Function of Primary T/W and Descent Rate

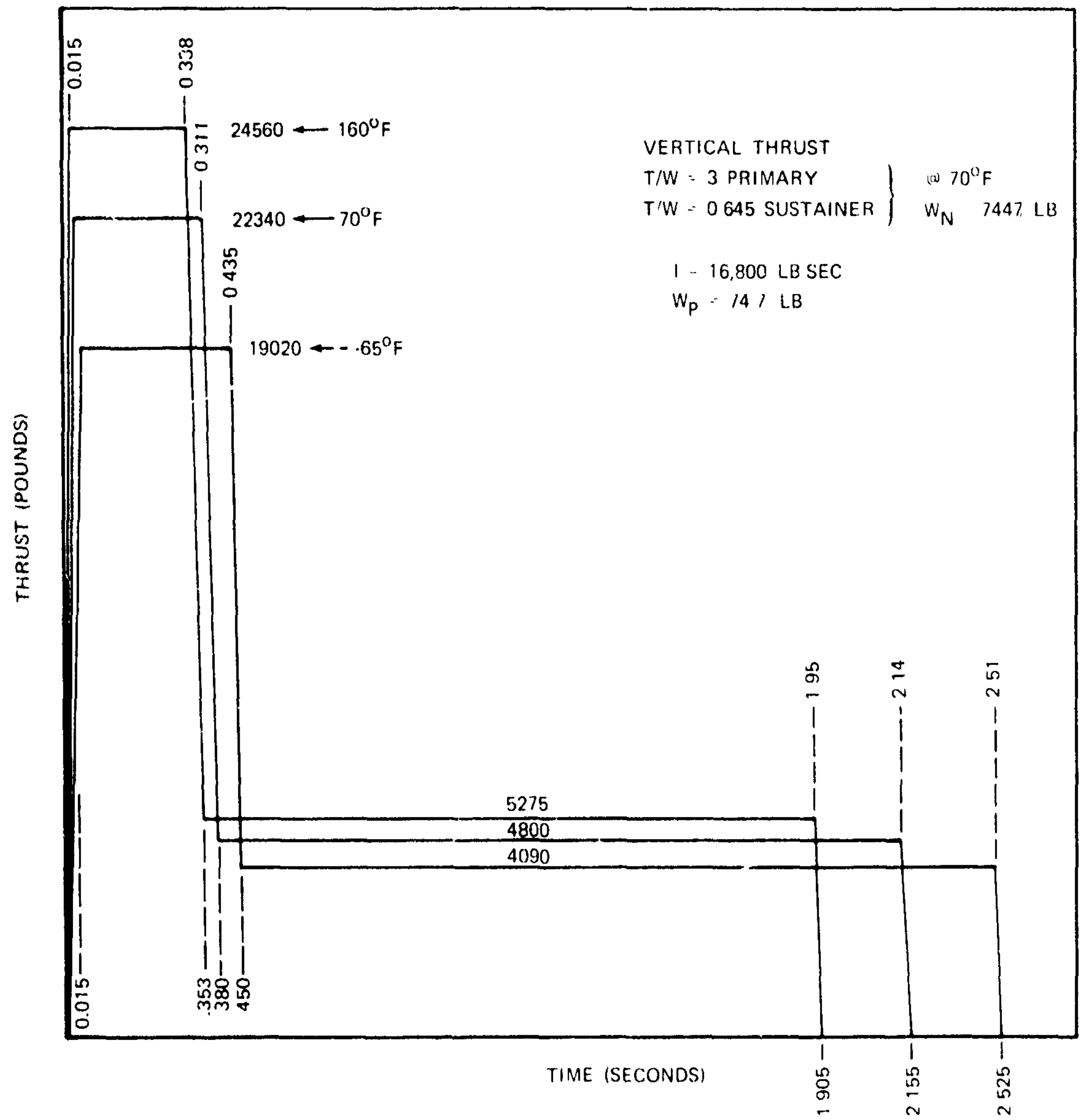


Figure 14. Thrust Versus Time for T/W = 3

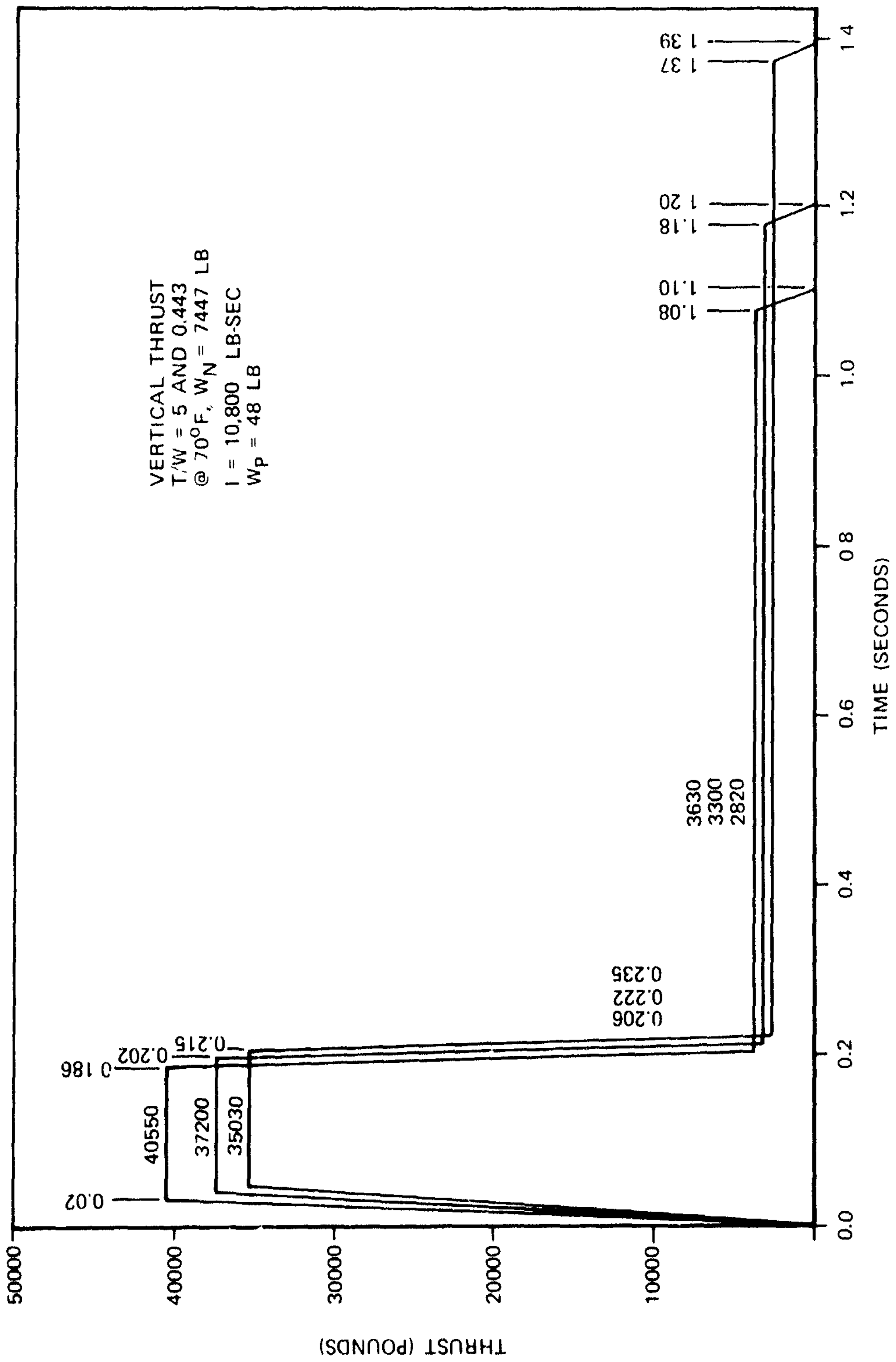


Figure 15. Thrust Versus Time for T/W = 5

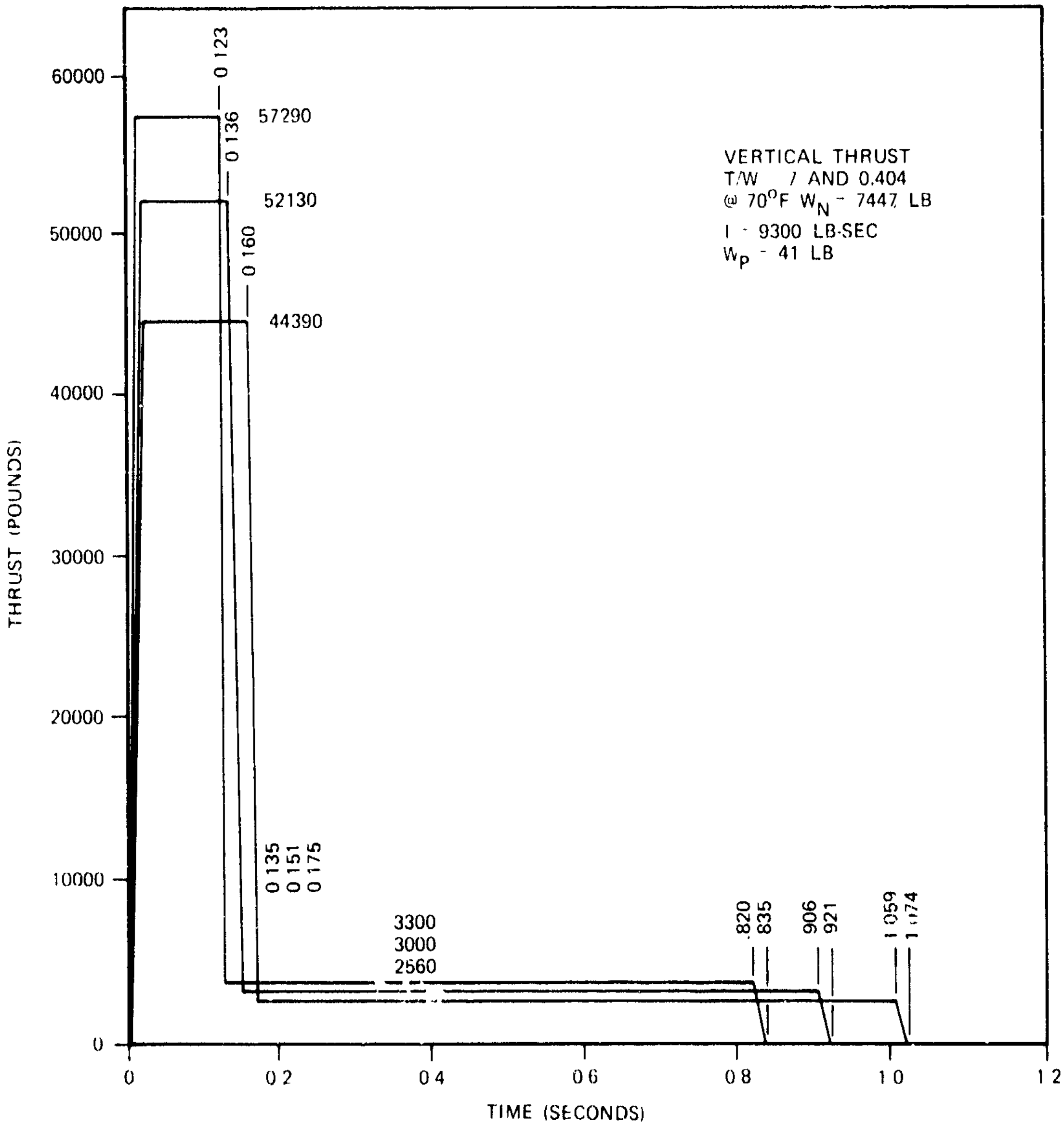


Figure 16. Thrust Versus Time for T/W = 7

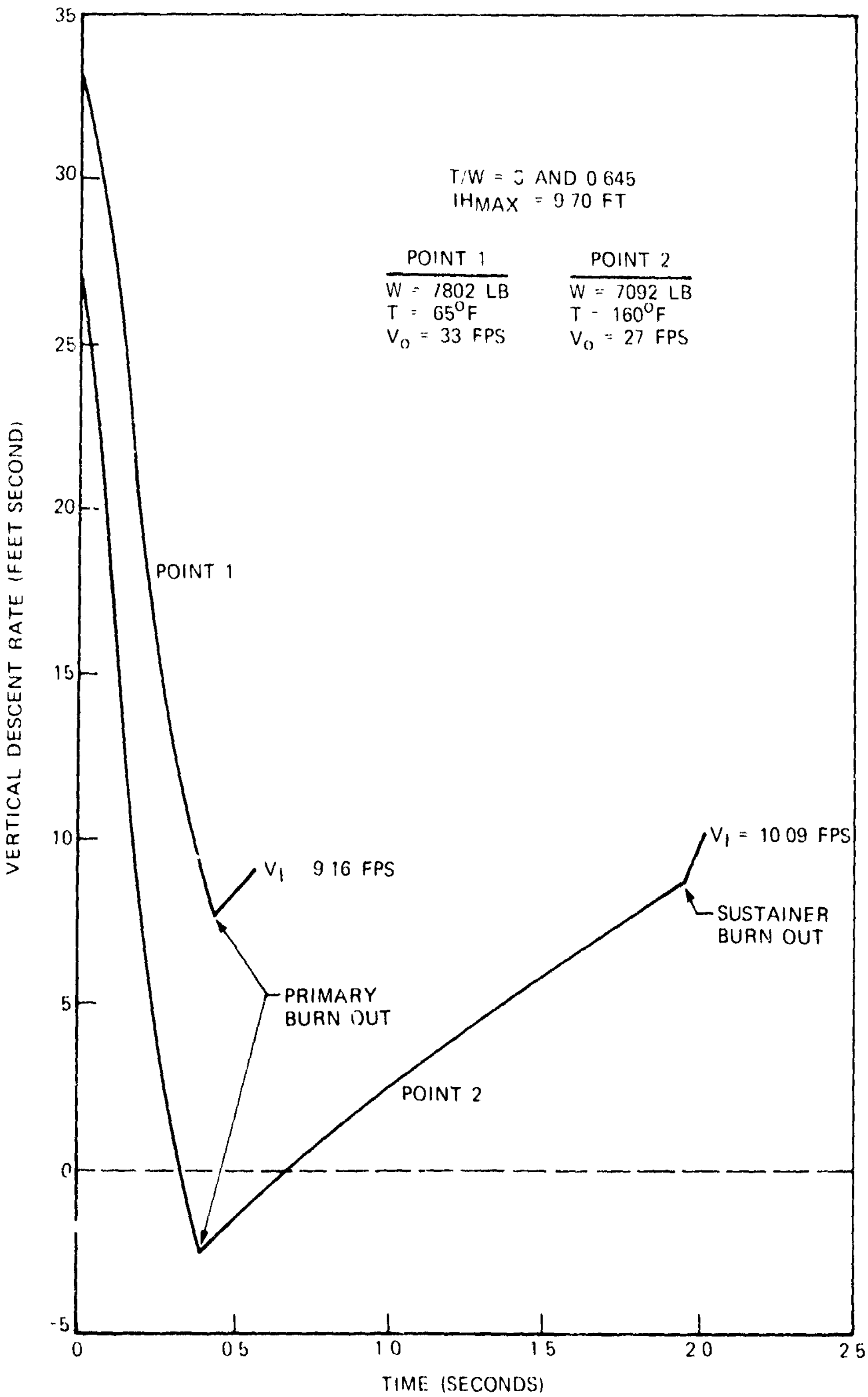


Figure 17. Capsule Velocity Versus Time at Design Points 1 and 2 for T/W = 3

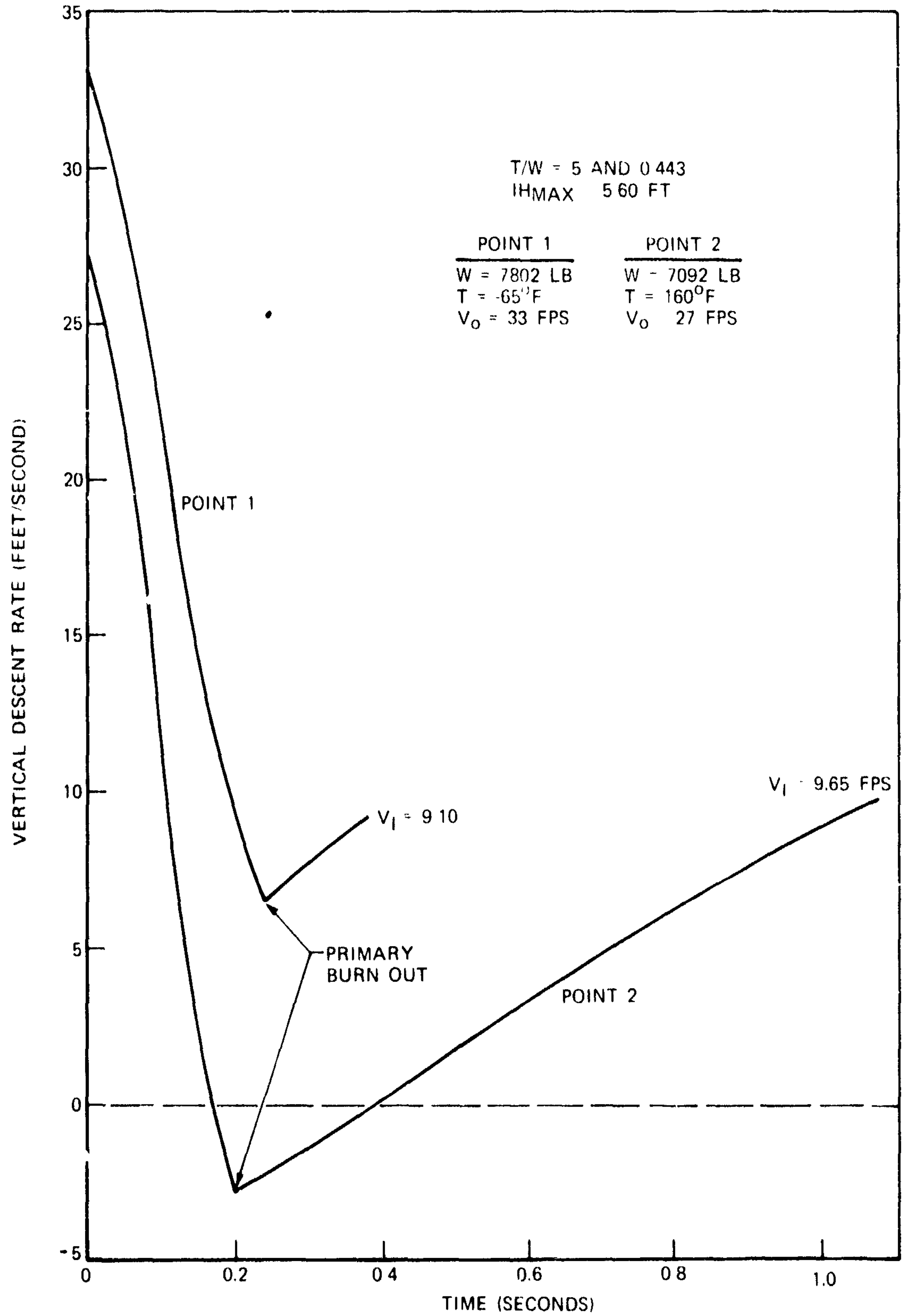


Figure 18. Capsule Velocity Versus Time at Design Points 1 and 2 for T/W = 5

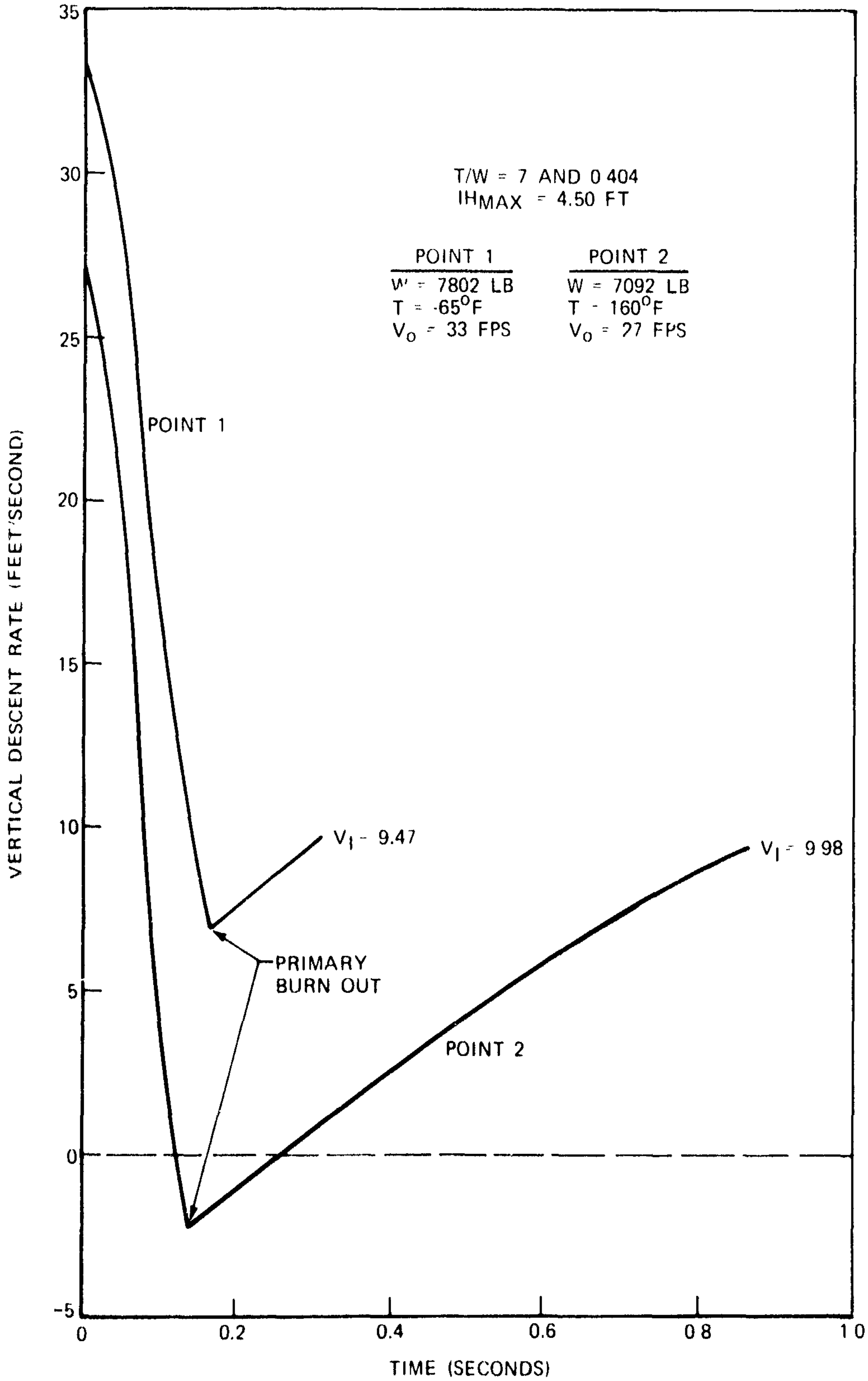
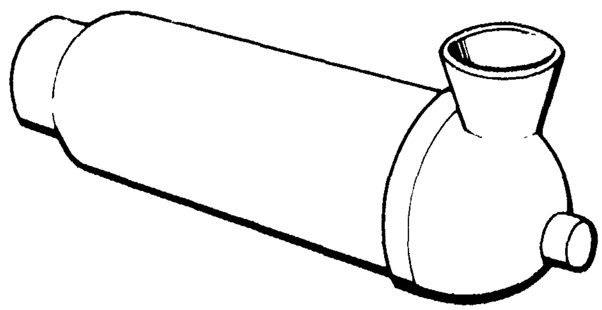


Figure 19. Capsule Velocity Versus Time at Design Points 1 and 2 for T/W = 7



The TE M-421 3 is a feasibility test motor for soft landing space capsules Two motors are used to slow the capsule just prior to impact The motors have nozzles that provide thrust in a direction 90 degrees to the case center line The motor is designed to operate reliably after exposure to space environment

MOTOR PERFORMANCE*

	Boost	Sustain
Burn Time/Ac Time (t_b/t_a), sec	0 418	0 960/1 428
Ignition Delay Time (t_d), sec	-	0 035
Burn Time Avg Ch Pr ($\bar{P}_b$), psia	1,990	600
Action Time Avg, Ch Pr ($\bar{P}_a$), psia		N/App
Maxium Cham Press (P_{max}), psia		2,400
Total Impulse (I_T), lbf sec		3,670
Burn Time Impulse (I_b), lbf sec	2,210	1,430
Motor Spec Imp (I_{mo}), lbf-sec/lbm	-	141
Prop Spec Imp (I_{sp}), lbf sec/lbm	-	239
Burn Time Average Thrust ($\bar{F}_b$), lbf	5,300	1,490
Action Time Average Thrust ($\bar{F}_a$), lbf		N/App
Maxium Thrust (F_{max}), lbf		6,500
Measured Thrust Coefficient (C_f)	1 46	1 36
Theoretical Thrust Coefficient (C_f^o)	1 61	1 51
Discharge Coefficient (C_d)	0 91	0 904

*60°F, Sea Level

WEIGHTS, lbm

Total Loaded	26 00
Propellant	15 31
Case Assembly	4 83
Nozzle Assembly	3 80
Igniter Assembly	0 75
Internal Insulation	0 87
External Insulation	0
Liner	0 25
Miscellaneous	0 19
Total Inert	10 65
Burnout	10 4
Propellant Mass Fraction	0 589

TEMPERATURE LIMITS

Operation	20°F to +180°F
Storage	20°F to +180°F

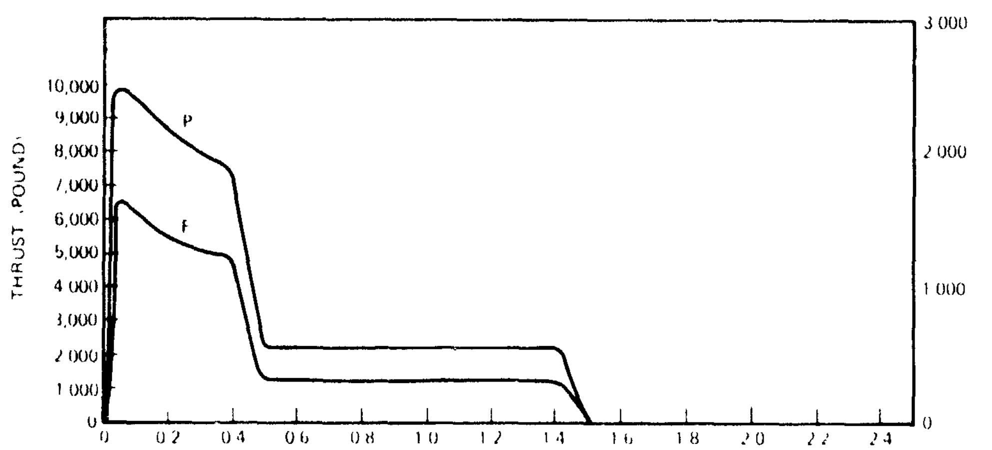


Figure 20. TE-M-421-3 Rocket Characteristics

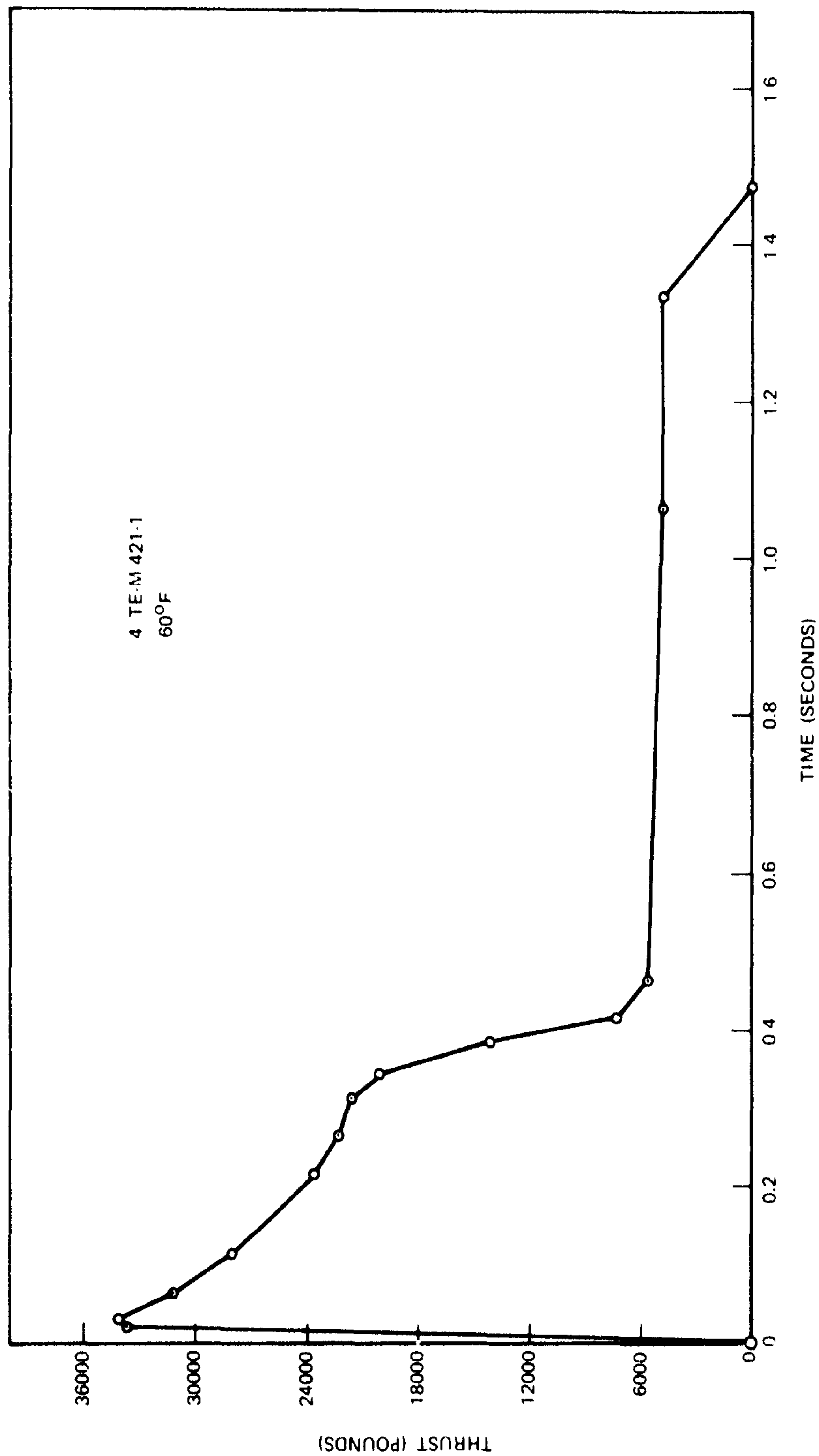


Figure 21. Thrust Versus Time for TE-M-421-1 at 60°F

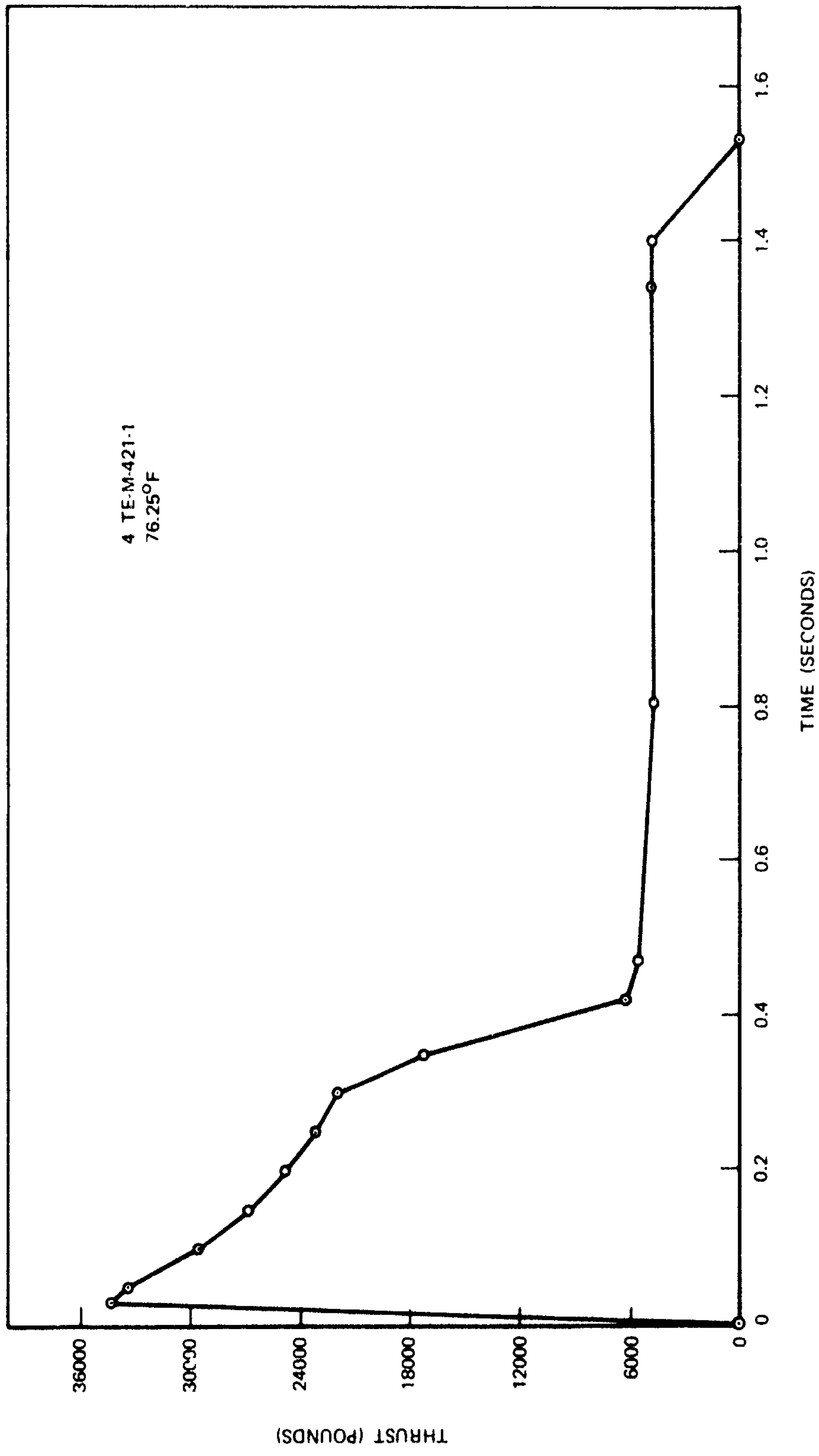


Figure 22. Thrust Versus Time for TE-M-421-1 at 76.25°F

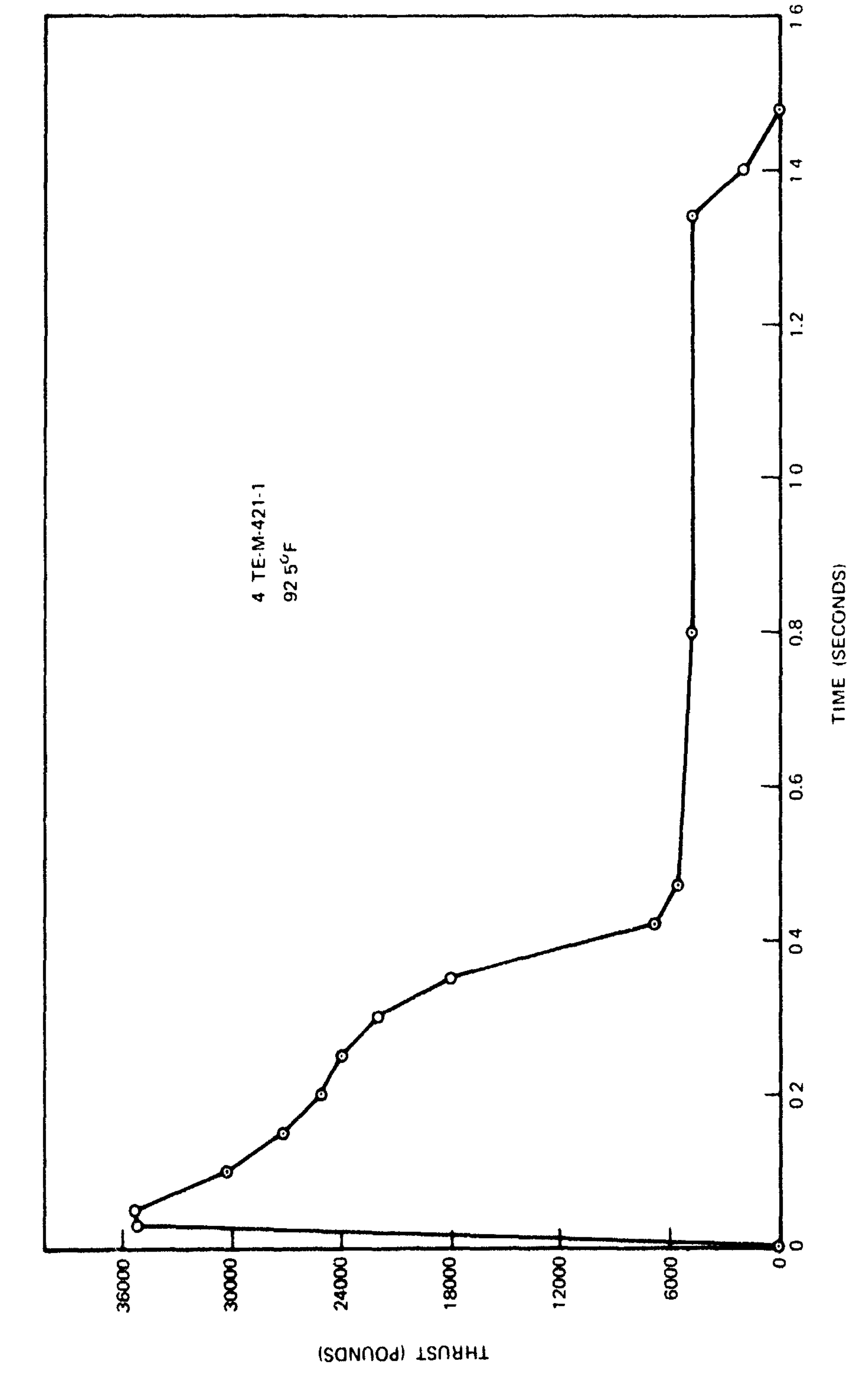


Figure 23. Thrust Versus Time for TE-M-421-1 at 92.5°F

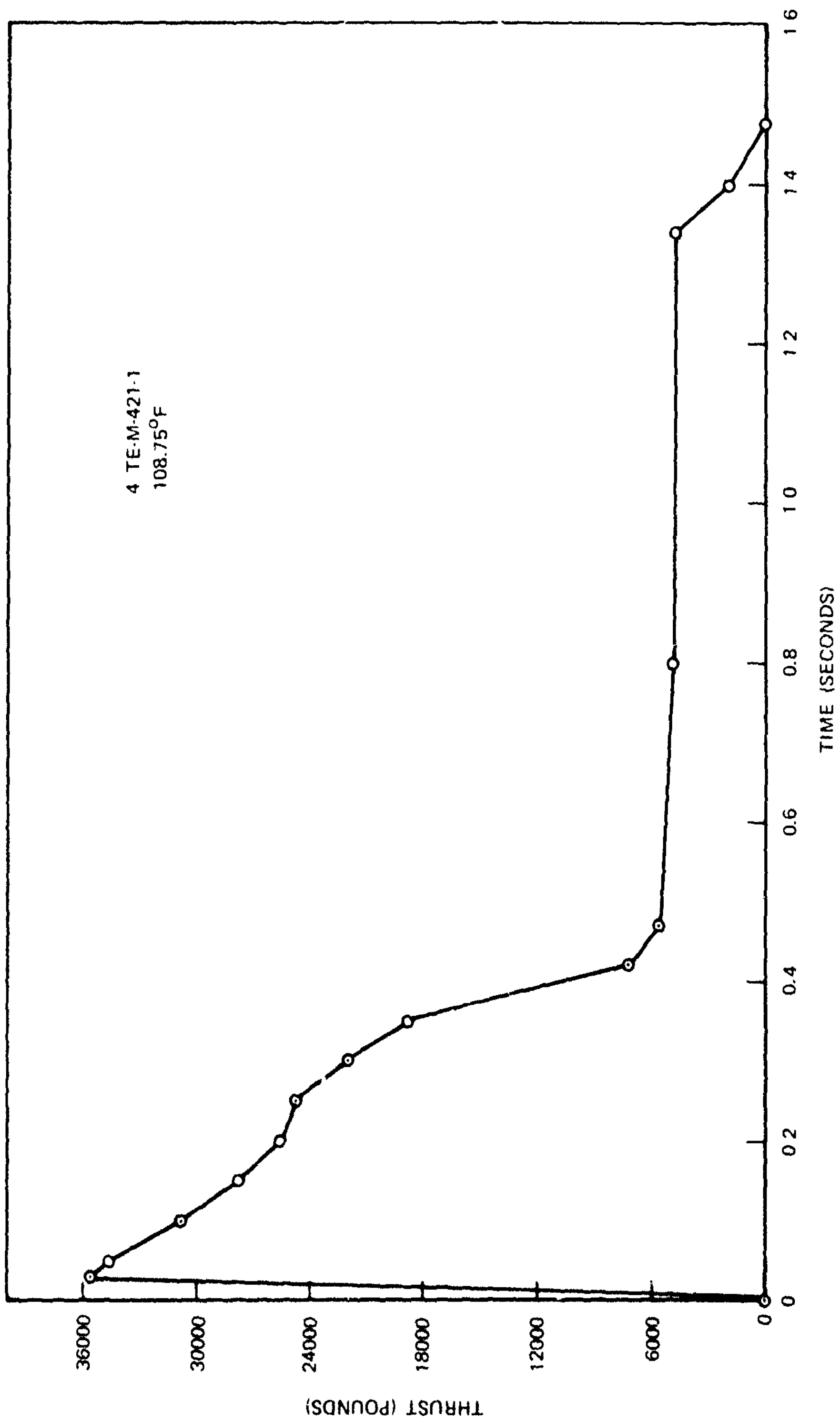


Figure 24. Thrust Versus Time for TE-M-421-1 at 108.75°F

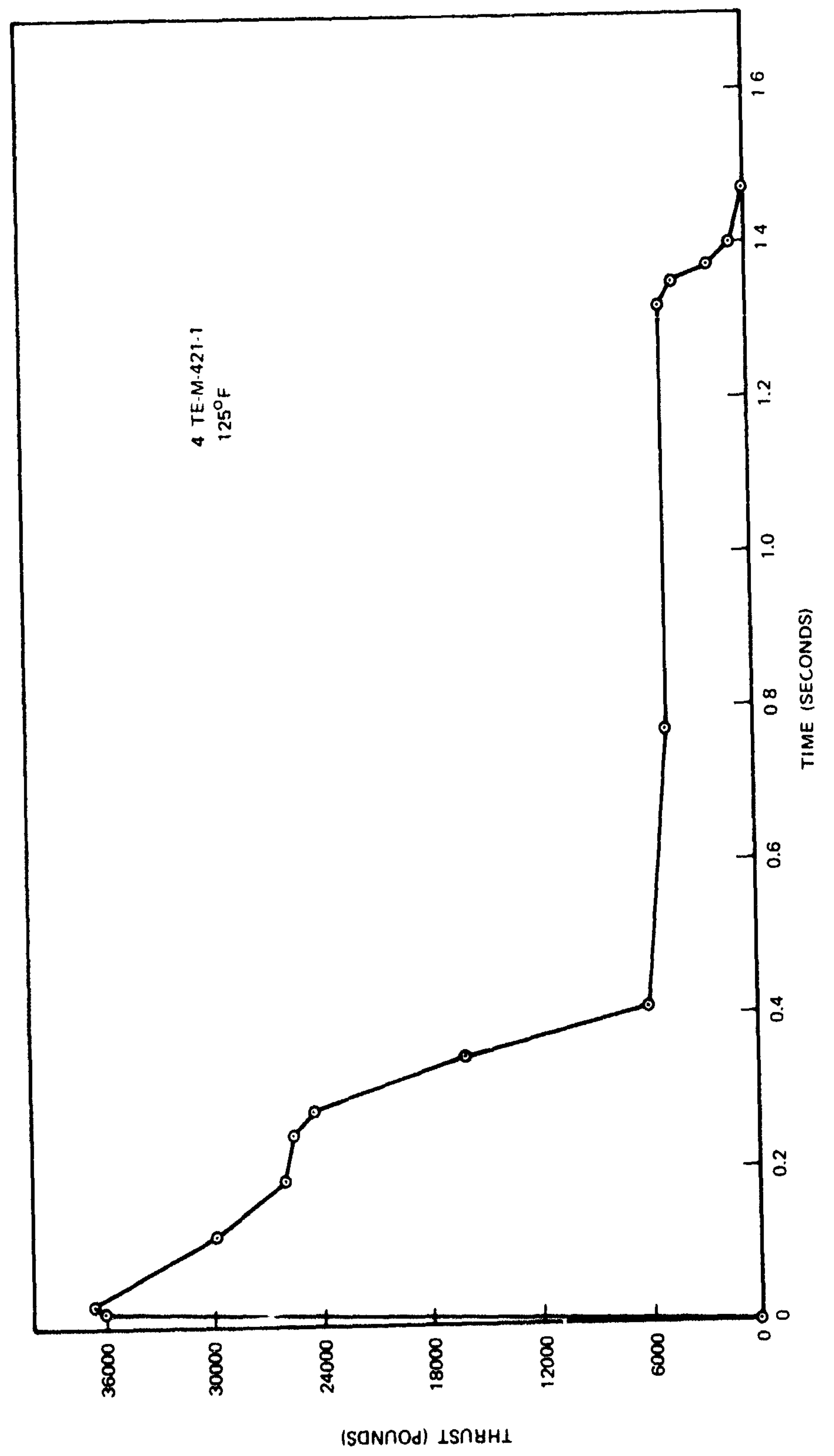


Figure 25. Thrust Versus Time for TE-M-421-1 at 125°F

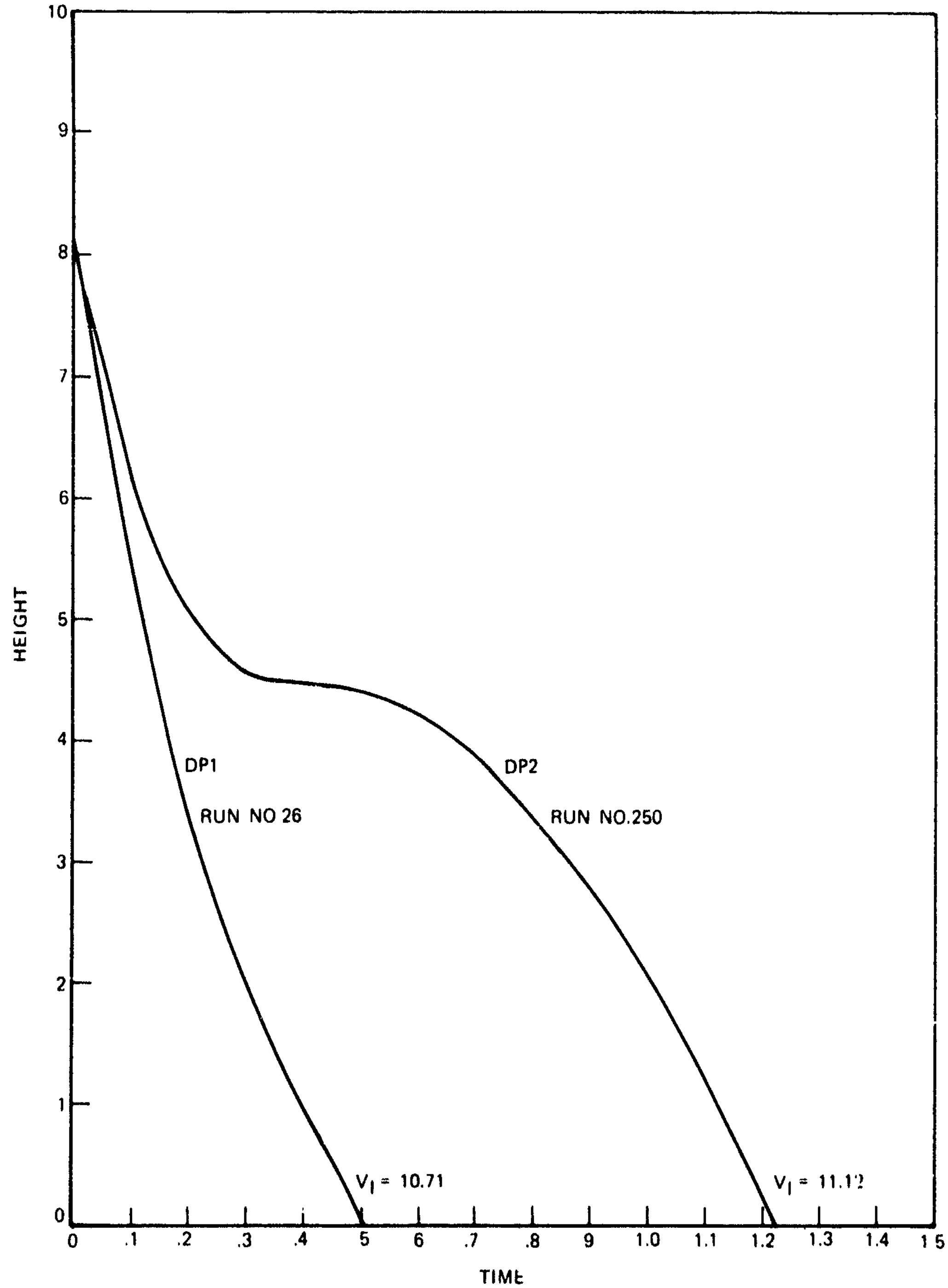


Figure 26. Capsule Height Versus Time, TE-M-421-1, Ground Slope = -1°, V_H = 34 fps

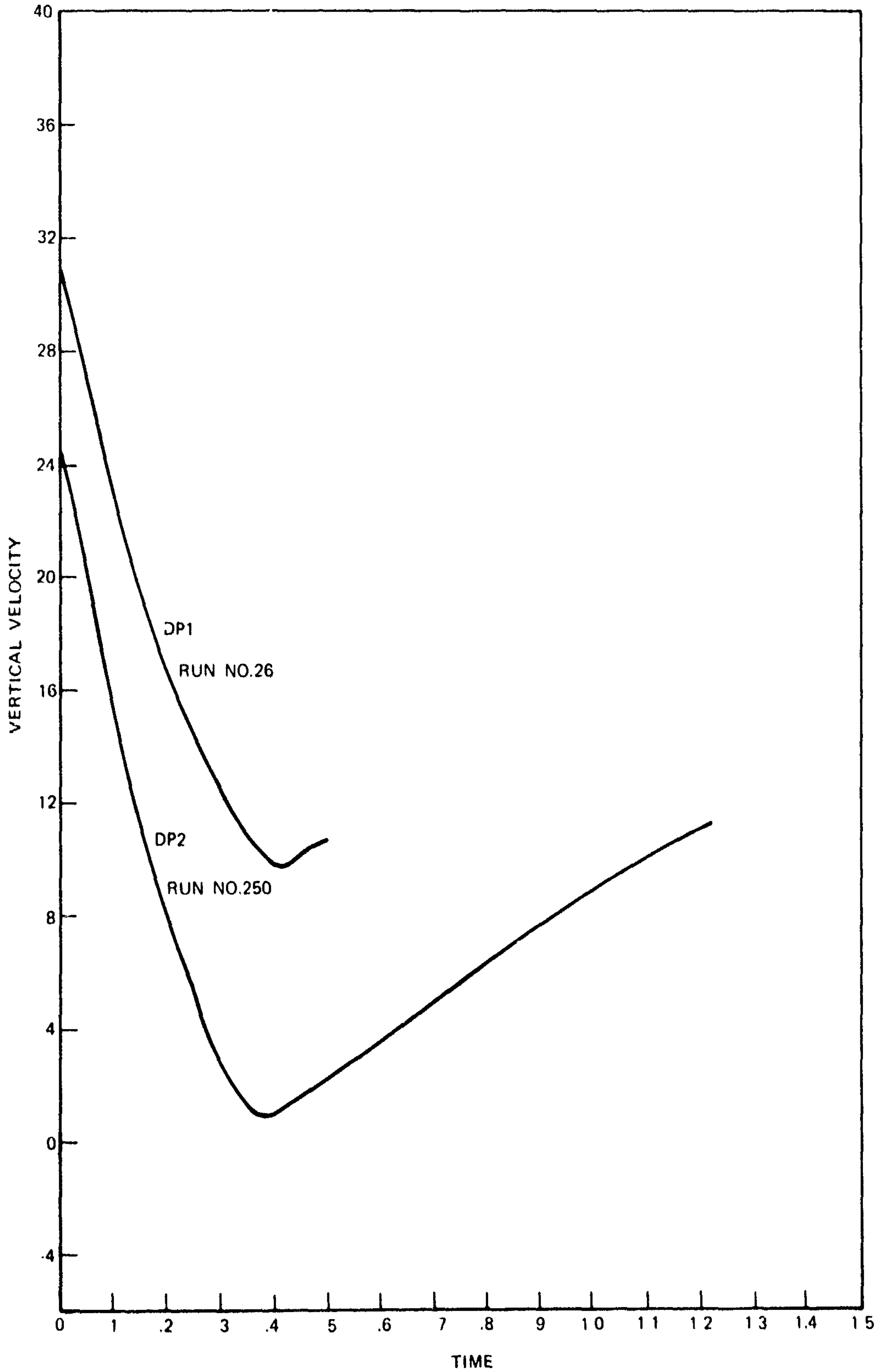


Figure 27. Capsule Velocity Versus Time, TE-M-421-1, Ground Slope = -1°, V_H = 34 fps

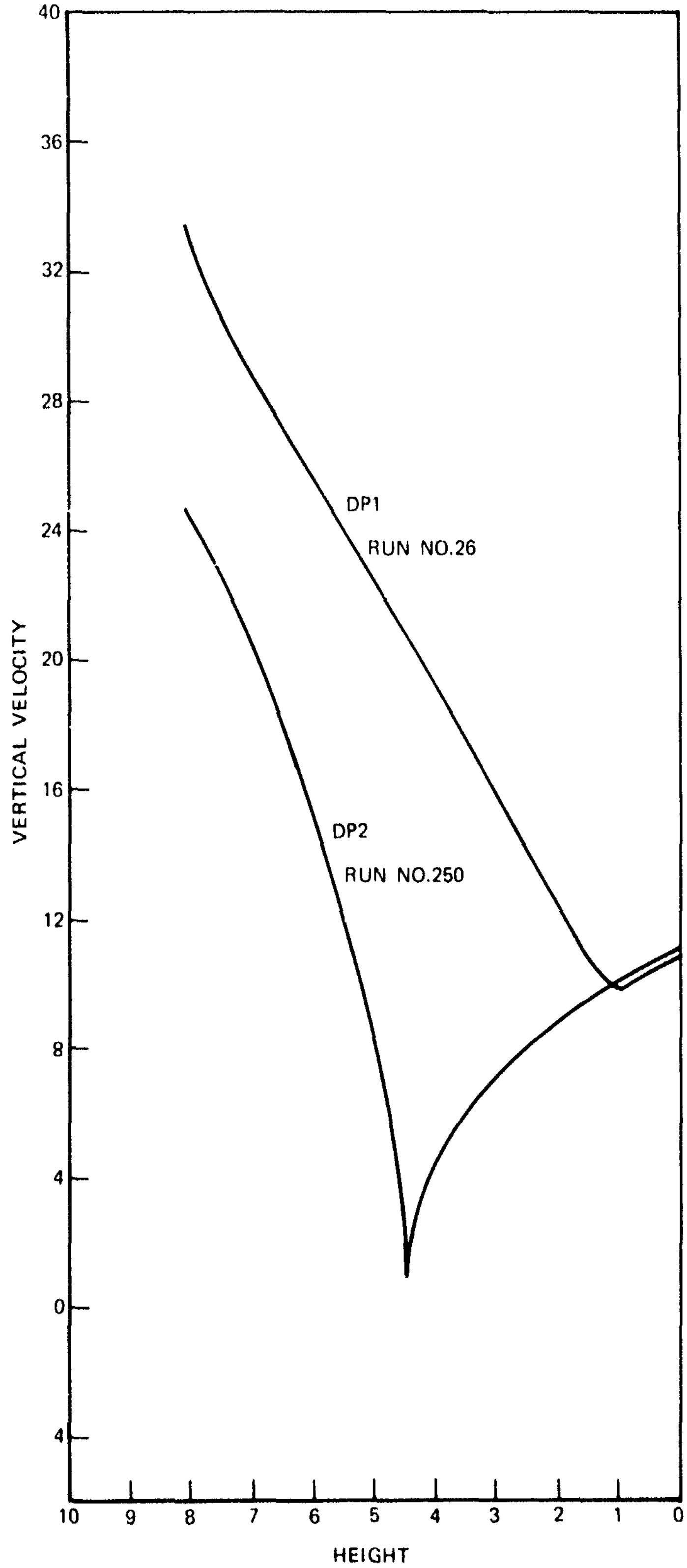


Figure 28. Capsule Velocity Versus Height, TE-M-421-1, Ground Slope = -1°, V_H = 34 fps

APPENDIX A

DROPPER COMPUTER PROGRAM

INPUT ARRAY AND PROGRAM LISTING

INPUT DATA ARRAY FOR SYSTEM PERFORMANCE COMPUTER PROGRAM

D(7)	Weight of Capsule System	(lbs)
D(8)	Altitude of Terrain	(ft)
D(9)	Parachute Diameter	(ft)
D(10)	Parachute Drag Coefficient	
D(11)	Module Reference Area	(ft^2)
D(12)	Module Drag Coefficient	
D(13)	Initial Altitude	(ft)
D(14)	Altitude of Retrorocket Ignition	(ft)
D(16)	Rocket Thrust Angle	(deg)
D(17)	Rocket Temperature	(°F)
D(18)	Rocket Thrust Factor	
D(19)	Parachute Drag Factor	
D(23)	Initial Vertical Velocity	(ft/sec)
D(24)	Time of Retrorocket Ignition	(sec)
D(25)	DELTA Time for Computations	(sec)
D(26)	Printing Interval for Output	(sec)
D(27)	Specific Impulse of Rocket	(lb-sec/lb)
D(28)	Thrust Angle	(deg)
D(29)	Initial Horizontal Velocity	(ft/sec)
D(30)	Oscillation Angle	(deg)
D(31)	Ground Slope	(deg)

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SOURCE LISTING

```
C  DECK TO COMPUTE RETROROCKET LANDINGS..........FERD....10/04/72       DROP0000
      PROGRAM DROPPER (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)            DROP0005
      DIMENSION P(50),D(50), BNTIME(15,3),THRUST(15,3),BRNTIM(15,3)      DROP0010
      COMMON /RKT/ TIM(15,21),THR(15,21),TIC(14,21),CAT(14,21)           DROP0020
    1 FORMAT(1H0,(F10.3,9F11.2,F11.1))                                   DROP0030
    2 FORMAT(1H0,16HGROUND IMPACT.....)                                  DROP0040
    3 FORMAT(1H1,20HINPUT ARRAY.... RUN ,I5///,(6F14.4))                 DROP0050
    6 FORMAT(2(1H0/),7X,4HTIME,6X,6HHEIGHT,3X,9HSINK RATE,4X,7HACC-G'S, DROP0060
     .4X,6HTHRUST,4X,7HVTHRUST,4X,7HCHTLOAD,4X,8HRIMPULSE,4X,5HRANGE,5X,DROP0070
     .8HVELOCITY,4X,6HENERGY)                                            DROP0080
    7 FORMAT(6F12.6)                                                     DROP0090
    8 FORMAT (//1H0,10HOUTPUT....)                                       DROP0100
    9 FORMAT (1H0,20HPROPELLANT WEIGHT - ,F8.2,5H LBS.)                  DROP0110
  101 FORMAT(1H ,(F10.3,9F11.2,F11.1))                                   DROP0120
  103 FORMAT (4(1H0/)50X,20H**** END OF JOB ****)                        DROP0130
  104 FORMAT (A1)                                                        DROP0140
      EQUIVALENCE (D(7),  WGT ),(D(8), ALTG ),(D(9),  DD  ),(D(10),  CDODROP0150
     . ),(D(11), BAREA),(D(12),  CDB  ),(D(13), ALTO ),(D(14), RKTALT),(DROP0160
     .D(15),  RKTT ),(D(16), RKTANG),(D(17), TEMP ),(D(18),FFRR),(D(19),DROP0170
     .FFCC),(D(23),VEL0),(D(24),RKTIM),(D(25),DELTIM),(D(26),RNTH)       DROP0180
     .,(D(27),SPIMP),(D(28),SKEW),(D(29),VELHO),(D(30),ALPHA)            DROP0190
     .,(D(31),GSLP)                                                      DROP0195
      EQUIVALENCE (P(1),TIME),(P(2),HGT),(P(3),VEL),(P(4), GB),(P(5),THRDROP0200
     .UST),(P(7),PDRAG),(P(8 ),RIMP),(P(5),VTHRST),(P(9),DISTH),         DROP0210
     .(P(10),VELH),(P(11),ENERGY)                                        DROP0220
      EQUIVALENCE (TIM(1,19), BNTIME(1,1)),(THR(1,19),THRUST(1,1))       DROP0230
      REAL NZLANG                                                        DROP0240
      NAMELIST /NEWSET/ D,RCNTR,BNTIME,THRUST                            DROP0250
      DATA ENDJOB /1H$/, RCNTR /-0.0/                                    DROP0260
      READ(5,7) D                                                        DROP0270
      READ(5,NEWSET)                                                     DROP0280
    4 CONTINUE                                                           DROP0290
```

SOURCE LISTING CONTINUED

```
      IF(RCNTR) 95,95,96                                          DROP0300
   95 RCNTR = 1.0                                                 DROP0310
   96 CONTINUE                                                    DROP0320
      IRUN = RCNTR                                                DROP0330
      WRITE(6,3) IRUN,D                                           DROP0340
      WRITE (6,3)                                                 DROP0350
      WRITE (6,6)                                                 DROP0360
      NPRT = 1                                                    DROP0370
        NDRAG = 1                                                 DROP0380
      NOUT=11                                                     DROP0390
      NFIRST = 1                                                  DROP0400
      DO 11 I=1,NOUT                                              DROP0410
   11 P(I)=0.0                                                    DROP0420
      NTH = RNTH                                                  DROP0430
      IFIRST=1                                                    DROP0440
      IROCK = 1                                                   DROP0450
      INT=0                                                       DROP0460
      SALPHA = SIN(ALPHA*0.017453292)                             DROP0470
      CALPHA = COS(ALPHA*0.017453292)                             DROP0480
      ACCH = 0.0                                                  DROP0490
      VELH = VELHO                                                DROP0500
      DISTH = 0.0                                                 DROP0510
      PVELH = 0.0                                                 DROP0520
      PDISTH = 0.0                                                DROP0530
      ACC=0.0                                                     DROP0540
      VEL = VELO                                                  DROP0550
      TIME=0.0                                                    DROP0560
      DIST=0.0                                                    DROP0570
      PVEL = 0.0                                                  DROP0580
      PDIST = 0.0                                                 DROP0590
      PAREA=3.14159*(DO**2)*.25                                   DROP0600
      HGTO=ALTO-ALTG                                              DROP0610
```

SOURCE LISTING CONTINUED

```
      FROCK = 0.0                                                       DROP0620
      THRUST = 0.0                                                      DROP0630
      VTHRST = 0.0                                                      DROP0640
      NZLANG =SKEW*0.017453292                                          DROP0650
      RIMP=0.0                                                          DROP0660
      PWGT = 0.0                                                        DROP0670
      DPWGT = 0.0                                                       DROP0680
      PRWGT = WGT                                                       DROP0690
      PRIMP=RIMP                                                        DROP0700
      HGT = HGT0                                                        DROP0710
      HGTG = 0.0                                                        DROP0715
      ALT = ALT0                                                        DROP0720
      CALL ATMOS(ALT,DEGR,SIGMA,RHO,THETA,DELTA,VSONIC,AMU,K)           DROP0730
      QUE=RHO*(VEL**2)*.5                                               DROP0740
       PDRAG = CDO*QUE*PAREA                                            DROP0750
      ENERGY = WGT*((VEL**2/64.348)+HGT)                                DROP0760
      WRITE(6,1)(P(I),I=1,NOUT)                                         DROP0770
C                                                                       DROP0780
C     RUNGE KUTTA                                                       DROP0790
    5 INT=INT+1                                                         DROP0800
C                                                                       DROP0810
      B=ACC*DELTIM                                                      DROP0820
      A = ACCH*DELTIM                                                   DROP0830
      C = VELH*DELTIM                                                   DROP0840
      F = VEL*DELTIM                                                    DROP0850
      G=FROCK*DELTIM                                                    DROP0860
      GO TO(10,20,30,40),INT                                            DROP0870
   10 B1=B                                                              DROP0880
      F1 = F                                                            DROP0890
      A1 = A                                                            DROP0900
      C1 = C                                                            DROP0910
      G1=G                                                              DROP0920
```

SOURCE LISTING CONTINUED

```
      B=B/2.                                                            DROP0930
      F = F/2.                                                          DROP0940
      A = A/2.                                                          DROP0950
      C = C/2.                                                          DROP0960
      G=G/2.                                                            DROP0970
      PDIST=DIST                                                        DROP0980
      PVEL=VEL                                                          DROP0990
      PDISTH = DISTH                                                    DROP1000
      PVELH = VELH                                                      DROP1010
      PRIMP=RIMP                                                        DROP1020
      GO TO 50                                                          DROP1030
 20   B2=B                                                              DROP1040
      F2 = F                                                            DROP1050
      A2 = A                                                            DROP1060
      C2 = C                                                            DROP1070
      A = A/2.                                                          DROP1080
      C = C/2.                                                          DROP1090
      G2=G                                                              DROP1100
      B=B/2.                                                            DROP1110
      F = F/2.                                                          DROP1120
      G=G/2.                                                            DROP1130
      GO TO 50                                                          DROP1140
 30   B3=B                                                              DROP1150
      F3 = F                                                            DROP1160
      A3 = A                                                            DROP1170
      C3 = C                                                            DROP1180
      G3=G                                                              DROP1190
      GO TO 50                                                          DROP1200
 40   B4=B                                                              DROP1210
      A4 = A                                                            DROP1220
      C4 = C                                                            DROP1230
      F4 = F                                                            DROP1240
```

SOURCE LISTING CONTINUED

```
      G4=G                                                              DROP1250
      B=(B1+2.*(B2+B3)+B4)/6.                                           DROP1260
      A = (A1+2.*(A2+A3)+A4)/6.                                         DROP1270
      C = (C1+2.*(C2+C3)+C4)/6.                                         DROP1280
      F = (F1+2.*(F2+F3)+F4)/6.                                         DROP1290
      G=(G1+2.*(G2+G3)+G4)/6.                                           DROP1300
   50 VEL=PVEL+B                                                        DROP1310
      DIST = PDIST + F                                                  DROP1320
      VELH = PVELH + A                                                  DROP1330
      DISTH = PDISTH + C                                                DROP1340
      RIMP=PRIMP+G                                                      DROP1350
      GO TO(60,70,60,70),INT                                            DROP1360
   60 TIME=TIME+DELTIM/2.                                               DROP1370
   70 CONTINUE                                                          DROP1380
      ALT=ALTO+DIST                                                     DROP1390
C                                                                       DROP1400
C     GET ATMOSPHERE DATA                                               DROP1410
C                                                                       DROP1420
      CALL ATMOS(ALT,DEGR,SIGMA,RHO,THETA,DELTA,VSONIC,AMU,K)           DROP1430
C                                                                       DROP1440
C     CALCULATE DRAG FORCES                                             DROP1450
C                                                                       DROP1460
      QUE=RHO*(VEL**2)*.5                                               DROP1470
       GO TO (300,301),NDRAG                                            DROP1480
  300  PDRAG = CDD*QUE*PAREA                                            DROP1490
  301     CONTINUE                                                      DROP1500
C                                                                       DROP1510
      BDRAG=CDB*QUE*BAREA                                               DROP1520
C                                                                       DROP1530
C     CALCULATE BODY MASS                                               DROP1540
C                                                                       DROP1550
      AMASS=WGT/32.174                                                  DROP1560
```

SOURCE LISTING CONTINUED

```
C                                                                    DROP1570
C     GO GET ROCKET THRUST                                           DROP1580
C                                                                    DROP1590
      HGTG =         DISTH*TAN(GSLP*0.017453292)                     DROP1595
      HGT = HGTO + DIST - HGTG                                       DROP1600
C                                                                    DROP1610
      ENERGY = WGT*((VEL**2/64.348)+HGT)                             DROP1620
C                                                                    DROP1630
      GO TO (31,51), IROCK                                           DROP1640
   31 HGT1 = -HGT                                                    DROP1650
      IF(HGT-RKTALT) 41,41,51                                        DROP1660
   41 HGT1 = -0.0                                                    DROP1670
      IROCK = 2                                                      DROP1680
   51 CONTINUE                                                       DROP1690
      GO TO(80,90,80,90),INT                                         DROP1700
   80 CALL ROCK (TIME,HGT1,RKTT,TEMP,RKTANG,RKTIM,RKTALT,FROCK,IFIRST) DROP1710
      FROCK=FROCK*FFRR                                               DROP1720
   90 VRTFRC = FROCK*COS (NZLANG)                                    DROP1730
      VTHRST = VRTFRC                                                DROP1740
      THRUST=FROCK                                                   DROP1750
      GO TO (91,93), NFIRST                                          DROP1760
   91 IF(FROCK.LE.0.0) GO TO 93                                      DROP1770
      PDRAG=PDRAG*FFCD                                               DROP1780
      WRITE (6,101) (P(I),I=1,NOUT)                                  DROP1790
      NFIRST = 2                                                     DROP1800
   93 CONTINUE                                                       DROP1810
C                                                                    DROP1820
C     CALCULATE NET FORCE                                            DROP1830
C                                                                    DROP1840
      IF(VEL) 201,201,200                                            DROP1850
  200 PDRAG = 0.0                                                    DROP1860
       IF(TIME.GT.0.1.AND.PDRAG.EQ.0.0) NDRAG = 2                    DROP1870
```

SOURCE LISTING CONTINUED

```
  201 CONTINUE
      IF(ABS(HGT).LE.RKTALT) PDRAG = PDRAG*FFCC
      IF(TIME.GE.RKTIM.AND.RKTALT.LT.0.) PDRAG = PDRAG*FFCC
      FNET = PDRAG+BDRAG+VRTFRC-WGT
      FVNET = BDRAG - WGT + CALPHA * (PDRAG + VRTFRC)
      FHNET = SALPHA * (PDRAG + VRTFRC)
      ACC = FVNET/AMASS
      ACCH = FHNET/AMASS
      G3V = ACC/32.174
      G3H = ACCH/32.174
      ACCT = FNET/AMASS
      G3 = ACCT/32.174
      GO TO(5,5,5,100),INT
C
C     OUTPUT
C
  100 INT=0
      IF(SPIMP) 203,203,202
  202 DPWGT = G/SPIMP
      PWGT = PWGT + DPWGT
      WGT = WGT - DPWGT
  203 CONTINUE
      IF(NPRT-NTH) 110,111,111
  111 CONTINUE
      WRITE(6,101)(P(I),I=1,NOUT)
      NPRT = 1
      GO TO 112
  110 NPRT = NPRT + 1
  112 CONTINUE
      IF(HGT)120,5,5
  120 WRITE(6,2)
      WRITE (6,101)(P(I),I=1,NOUT)
```

SOURCE LISTING CONTINUED

```
      IF(SPIMP.GT.0.0) WRITE (6,9) PWGT                              DROP2200
      WGT = PRWGT                                                    DROP2210
      READ (5,134) FOLAST                                            DROP2220
      IF(FOLAST.EQ.ENDJOB) GO TO 102                                 DROP2230
      BACKSPACE 5                                                    DROP2240
      RCNTR = RCNTR + 1.0                                            DROP2260
      READ (5,NEWSET)                                                DROP2250
      GO TO 4                                                        DROP2270
  102 WRITE (6,103)                                                  DROP2280
      STOP                                                           DROP2290
      END                                                            DROP2300
```

LIST OF SYMBOLS

DP1	Design Point 1
DP2	Design Point 2
E	Ignition Height Error
I	Rocket Impulse
IHmin	Minimum Ignition Height
IHmax	Maximum Ignition Height
SL1	Altitude Lost at DP1
SL2	Altitude Lost at DP2
σ	Thrust-Temperature Coefficient (0.0011/°F)
t	Time
t_C	Rocket Burn Time at Minimum Temperature
t_N	Rocket Burn Time at Nominal Temperature
t_H	Rocket Burn Time at Maximum Temperature
T	Thrust
T/W	Thrust to Weight Ratio
T_C	Thrust at Minimum Temperature
T_N	Thrust at Nominal Temperature
T_H	Thrust at Maximum Temperature
TE_H	Temperature, Max
TE_N	Temperature, Nom
TE_C	Temperature, Min
V	Velocity
VO	Initial Capsule Vertical Velocity
VO1	Initial Capsule Vertical Velocity at DP1
VO2	Initial Capsule Vertical Velocity at DP2

LIST OF SYMBOLS (Concluded)

V_I	Vertical Velocity at Impact
V_H	Horizontal Velocity
V_{RBO1}	Vertical Velocity at Rocket Burn-Out, DP1
V_{RBO2}	Vertical Velocity at Rocket Burn-Out, DP2
W_L	Capsule Weight, Minimum
W_N	Capsule Weight, Nominal
W_H	Capsule Weight, Maximum
W_P	Propellant Weight